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THE PHYSICS OF SOLAR CORPUSCULAR STREAMS AND THEIR INFLUENCE ON THE UPPER ATMOSPHERE OF THE EARTH

Fizika solnechnykh korpuskuliarnykh potokov i ikh vozdeistvie na verkhniuiu atmosferu Zemli

Moscow, Izdatel'stvo Akademii Nauk SSSR, 1957.
pp. 8-39, 40-50, 69-86, 144-158, 167-181, ~~261-268~~ 268.

Selected articles translated
by John Miller and Judith Danner

for

Geophysics Research Directorate, AF Cambridge Research Center, Cambridge, Mass., by the American Meteorological Society, Contract number 19(604)-1936
T-RC-13 +

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DISCUSSION OF THE POSSIBLE SOURCES OF GEOACTIVE CORPUSCLES IN THE SOLAR ENVELOPE

by

E. R. Mustel'

1. METHODS OF STUDYING CORPUSCULAR STREAMS

Undoubtedly, the most important problem in the study of corpuscular streams is the localization of the sources of corpuscles in the solar envelope. This is a very important problem because the methods of predicting the invasion of the earth's atmosphere (its upper layers) by solar corpuscles somehow must derive from the known sources of ejection of solar material. Various methods can be used to determine the source of corpuscles in the solar envelope:

1) comparison of the different formations and phenomena in the solar envelope with geomagnetic and ionospheric disturbances, amplifications and attenuations of the intensity of cosmic rays and other effects on the earth;

2) attempts at direct spectroscopic detection of corpuscular streams en route from the sun to the earth;

3) study of the possible mechanisms of ejection of atoms from the sun and their further study.

In practice, one must combine these methods and add others to solve the problem. Before proceeding to a direct discussion of the whole problem, we will make some remarks about the above methods.

When using the first method, the method of comparison, we must first turn to the directly observable formations in the solar envelope. Only when there are no details visible on the sun which could be considered the source of various effects on earth (geomagnetic disturbances, etc.), should different hypotheses be introduced on the nature of corresponding regions in the solar envelope not marked by directly observable formations. Such "hypothetical" regions include, in particular, Bartels' M-regions, which are frequently cited in discussions of this problem.

The spectroscopic methods of detecting and studying corpuscular streams, which will be considered in other papers at this conference, are very important and interesting; they are usually based on the assumption that the optical thickness of corpuscular streams along the line of sight, for certain spectral lines, can be either comparable to unity or not much less than unity.

Thus, the corpuscular stream can form its absorption line shifted from the normal position (due to the movement of atoms from the sun). When superimposed on its corresponding ordinary absorption line in the solar spectrum, this line must cause a certain asymmetry in the ordinary line. There are reasons for assuming that if this effect actually does exist, it should be observed first of all in the most intense lines of the solar spectrum, in the H and K lines of Ca^+ and in the first lines of the Balmer series of hydrogen, especially in line H_α with the wavelength $\lambda = 6563$ Å.

Above, we said that the stream can form its own absorption line. However, this does not exclude the possibility that, due to very peculiar, anomalous conditions of the excitation of atoms in the stream, emission effects will predominate over absorption effects. In this case, the stream will form an emission line rather than an absorption line, then the asymmetry effect on the basic absorption line of the solar spectrum will be opposite in sign to the effect which would be observed were absorption to predominate.

Unfortunately, thus far attempts to detect the effects of absorption from corpuscular streams have not led to unambiguous and indisputable results. In any case, the asymmetry effect lies at the threshold of accuracy of contemporary photographic and photoelectric observations and, thus, a great deal of work is required in this area. A. B. Severnyi, at the Crimean Astrophysical

Observatory of the Academy of Sciences, obtained very interesting results on the asymmetry effects due to the additional emission of atoms in corpuscular streams, and will present them in his paper.

One should note the intrinsic fault of the above method. When this method is used, it is extremely difficult to determine the final direction of the streams coming from the sun, since the ionized calcium and hydrogen atoms should be ionized rather quickly in coming from the sun, whereupon the absorption processes in the corresponding line cease. In other words, these effects should be substantial in the immediate vicinity of the sun's surface. Further, study of the different solar phenomena shows that there are certain factors (no doubt of an electromagnetic nature) which can deflect the streams in various directions from their initial direction. In this connection, the effects of asymmetry in absorption give us an idea only of the localization of atoms in the streams near the sun's surface, but do not give an accurate indication of the direction of ejection of these atoms. Figure 1 illustrates this. In the first case, the direction of the atoms ejected from the active region AA+) is indicated by the letter B, in the second case by C. These atoms can create possible absorption activity only to distances delineated by line aa. Therefore, we cannot determine the final direction of the ejected atoms. The same applies to emission effects. The inten-

Figure 1. An explanatory drawing of the absorption and emission effects from corpuscular streams.

+) Generally, however, this zone should differ somewhat for the H and K lines and the lines of the Balmer series.

sity of these effects (besides the other factors) should be determined by the density of the matter in the stream, which decreases with distance.

We would be able to make considerable progress if a systematic study could be made of the asymmetry effects in the far ultraviolet lines L_α, L_β ... , of the Lyman series of hydrogen. These lines start from the ground levels of the hydrogen atom and, due to the extremely high hydrogen content of the solar envelope, must be exceptionally strong; therefore, it is quite possible that the effect of ionization in the given case may prove to be substantial at far greater distances from the sun than is the case for the H and K lines and the lines of the Balmer series. This zone is indicated by the line bb in figure 1.

However, even here there are difficulties. First, the lines of the Lyman series can be studied only by using high altitude rockets. Second, only integral solar radiation is recorded by contemporary rockets, i.e. the radiation of the entire solar disk. Further, as follows from figure 1, in studying the direction of the streams we must investigate the effects of asymmetry in lines at different points of the solar disk. In other words, only a study of the displacement of the effective center of the "corpuscular" line of absorption (or the emission line) on the disk can give an indication of the direction of the stream. These same things must be considered when one studies the possibility of radio emission from corpuscular streams. Since the density of the matter decreases with distance from the sun, probably even in this case we would get information on the movement of atoms only in the immediate vicinity of the sun.

We will comment briefly here on the mechanisms of corpuscular ejection from the sun. It is quite evident that in working out the mechanism of the flow of matter from the sun, we should begin our study by establishing the forces that cause this flux. Furthermore, the regularity of this mechanism

must be checked constantly on the basis of regularities in the effects of these streams on the earth, such as the 27-day recurrence of geomagnetic disturbances, seasonal regularities in geomagnetic activity, etc.

Keeping these general remarks in mind and since the study should begin with the various directly observable forms of solar activity, we will discuss the various formations on the sun's surface, examining them as possible sources of solar geoeffective corpuscles. We will start with sunspots.

2. SUNSPOTS

Sunspots were discovered much earlier than the other active formations on the sun. They are the most conspicuous and easily observed details of the sun's surface. This is why the comparison of geophysical manifestations of solar activity and solar phenomena began with sunspots. Very abundant data have already been gathered on comparisons of this kind, from which it follows, apparently, that sunspots are not an important source of corpuscular emission and that the "geoeffectiveness" of sunspots "discovered" by various authors is not due to these spots but to other forms of solar activity closely related to sunspots. Among these forms are faculae, flocculi and chromospheric flares, about which something will be said later.

However, for the sake of clarity we will formulate the present state of the question. Even in 1929, when making a comparison of sunspots and geomagnetic disturbances, the Greenwich astronomers, Greys and Newton, found (see [1], pp. 188-190) that the number of spots in the central part of the solar disk at the moment a magnetic storm begins is greater than the number of spots on magnetically calm days, and this increase becomes conspicuous beginning with quite intense storms and is most sharply expressed in the case of very large storms. This conclusion was confirmed in 1948 by Newton [2] on the basis of more complete data. We give his graph here (figure 2). The days, sity of these effects (besides the other factors) should be determined by the density of the matter in the stream, which decreases with distance.

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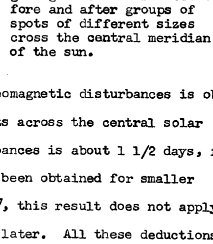

Figure 2. The intensity of geomagnetic disturbances before and after groups of spots of different sizes cross the central meridian of the sun.

We see that actually a marked increase in geomagnetic disturbances is observed after the passage of a large group of spots across the central solar meridian. For curve A the average lag of disturbances is about 1 1/2 days, for curve B about 4 days. No clear relationship has been obtained for smaller spots. Let us note that according to Allen [3], this result does not apply to chromospheric flares, which will be discussed later. All these deductions could be interpreted such that only intense magnetic storms would be associated with spots, while most weak and moderate storms would not be related to the presence of spots on the solar disk. However, it is difficult to agree with such a conclusion from the physical point of view. A number of other factors can be added here. We know that very frequently stable strong 27-day sequences of geomagnetic disturbances are observed in absence of sunspots (especially in years preceding minimum solar activity), but even when there are spots geomagnetic disturbances are not stable - they appear and vanish.

Obviously, this contradicts the fact that geomagnetic disturbances recur, which indicates the presence of some stable source of corpuscles. In this respect, apparently no one seriously considers sunspots to be a source of geoeffective corpuscles. Further, it must be mentioned that sunspots play a very great role in the physics and geometry of corpuscular streams. Thus, for example, sunspots with a strong magnetic field can deflect the atoms and ions of a corpuscular stream that are ejected from adjacent areas of the solar envelope. The magnetic field of sunspots can increase the solid angle of corpuscular streams and, finally, can decelerate the moving corpuscles, etc.

3. FACULAE AND FLOCCULI

We feel it would be useful here to elucidate some of the basic definitions of solar science, since at this conference there are many representatives of specialities allied to ours. Almost everyone knows what sunspots are, but the nature of the other formations of the solar envelope are not always clearly understood.

Let us recall that basically all the solar radiation which we observe in the optical region comes from a comparatively thin gaseous layer, 200-300 km thick, called the photosphere. Basically, the absorption lines also form in this layer (which has an average temperature of the order of 6000°). Sometimes, for various reasons, the photosphere is arbitrarily divided into two layers: the lower, called the photosphere, and the upper, called the reversing layer. This division of the photosphere is related to the fact that the continuous solar spectrum is usually determined by the lower layers of the photosphere, while to a considerable extent the absorption lines stem from the upper layers. However, this division of the photosphere into two layers is highly arbitrary, and so when we speak of the photosphere we will have both layers in mind.

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Above the photosphere there is a considerably more extensive and rarefied layer called the chromosphere; it is about 15,000 km thick. Finally, above the chromosphere is the vast outer solar envelope, the solar corona, whose basic properties are a very high kinetic temperature (of the order of one million degrees) and very low density of matter.

Figure 3.
Sunspots and faculae.

Figure 4.
Defining faculae and flocculi.

Sunspots and faculae generally appear in the photospheric layers. Faculae appear as lighter areas on the solar disk when the sun is viewed through a telescope (figure 3). As a rule, sunspots are surrounded by faculae, although faculae can also be observed outside the spots. Faculae are almost invisible in the central parts of the disk. Spots have a lower temperature and faculae a higher temperature +) than the adjacent layers of the solar photosphere.

The chromospheric layers above the faculae are called flocculi (figure 4). Atoms in flocculi are in a state of higher excitation than those in the adjacent layers of the chromosphere situated at the same levels. Further, since the central parts of the strongest lines of the solar spectrum, basically the H and K lines of Ca^+ and the H_α line, occur in the chromosphere, the emission in the central parts of these lines must be higher above the faculae, i.e. in the flocculi. Therefore, if we photograph the solar disk in the central parts of the H and K lines or H_α, it should be bright in places where there are flocculi.

Figure 5, obtained on the dual spectroheliograph of the Crimean Astrophysical Observatory, shows a photograph of the sun taken in the central parts of the H_α line of hydrogen (figure 5a) and a photograph taken in the light of one of the lines of ionized calcium (figure 5b). Photographs made in the light of any spectral line are called spectroheliograms. In figure 5 it is evident that the bright calcium flocculi occupy a much larger area than the bright hydrogen flocculi. According to M. N. Gnevyshev and R. S. Gnevysheva, calcium flocculi coincide in area and shape with the faculae and thus an active region ++) is best represented when it includes spots, faculae, flocculi and the prominences associated with spots. The dark, irregularly shaped bands, which are especially apparent in the hydrogen spectroheliogram, are prominences located above the chromosphere. They conceal the solar disk from us in

+) Actually, the law of temperature distribution in a facula is very complex.

++) Faculae can be observed clearly only on the limbs of the solar disk, while flocculi can be observed over the entire disk.

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such places and seem darker by contrast.

The author surmises that faculae or calcium flocculi (which are the same from the point of view of the position of the active region on the solar disk) are one of the chief sources of geoeffective solar corpuscles.[+)] In 1942, the author [4] discovered that the passage of each facular field across the visible center of the solar disk is accompanied, after a fixed time interval (several days), by geomagnetic disturbances of various intensities. This finding was verified in 1942-1945 by the data of the Solar Service of the P. K. Shternberg State Institute of Astronomy[++)] and then by the data of the Meudon synoptic charts for this same period. Furthermore, the comparisons were checked against the data of Meudon synoptic charts for 1929-1935.

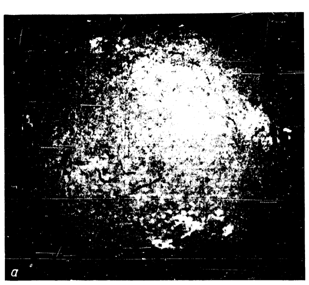

Figure 5.
Hydrogen and calcium flocculi.

+) This agrees, in particular, with the fact that floccular fields are usually relatively stable formations (as opposed to spots) for many rotations of the sun.

++) Sluzhba Solntsa Gosudarstvennogo astronomicheskogo instituta imeni P. K. Shternberga.

Further, in 1951-1954 a continuous check on this finding was made by the Solar Service of the Crimean Astrophysical Observatory of the Academy of Sciences of the U.S.S.R.[+)] This is a particularly important period, because for it we have photographs of the calcium flocculi for every day of the summer and nearly every day of the year. The material was provided by the above mentioned services and those of the other observatories of the U.S.S.R.

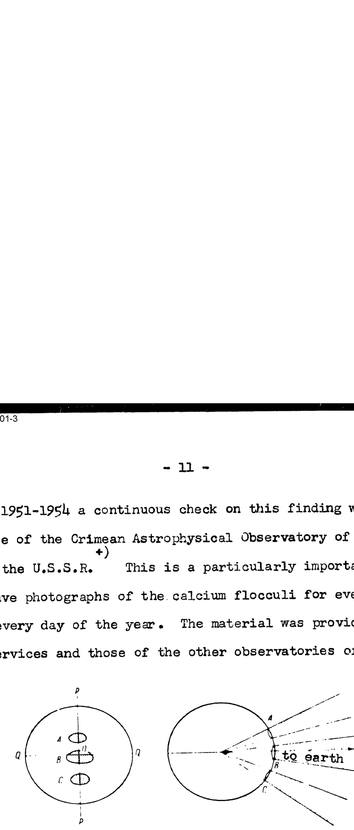

Figure 6. The radiality of corpuscular streams from flocculi.

All these comparisons confirmed our finding. From the geometrical point of view, this means that the corpuscles travel radially from the calcium flocculi, which is easy to understand from figure 6 where QQ is the solar equator. The shaded areas A, B, C are flocculi which are moving across the central meridian of the sun POP due to the sun's rotation; PP is the axis of rotation of the sun. Flocculus B is traveling across the visible center of the solar disk. If the corpuscles actually travel radially, the streams from flocculi A and C will bypass the earth and the stream from flocculus B will approach the earth sometime after the flocculus crosses the central meridian, after which the earth will be inside the stream. However, it should be stipulated that radial streams from the sun cannot cause a large part of the geomagnetic disturbances in all years of the 11-year cycle of solar activity. We know that the mean latitude of different formations on the sun changes with the

+) Sluzhba Solntsa Krymskoi astrofizicheskoi observatorii Akademii Nauk SSSR phase of the solar cycle. Spots, faculae and flocculi have practically the same law of change of latitude. The mean latitude of these formations is minimum in the year of minimum solar activity. The flocculi and spots are closest to the equator at this time. Their mean latitude is of the order of 7°. A new cycle of solar activity begins immediately after the minimum and all the enumerated formations are observed in high latitudes, on an average at latitudes of $\pm 25^{\circ}$. After this, the mean latitude of the spots and flocculi begins to decrease and around the solar activity maximum it is near $\pm 15^{\circ}$. The decrease in latitude ends in a year of minimum solar activity, then the whole process is repeated. In connection with these very important laws, for two to three years after a minimum all flocculi are located at such high heliographic latitudes that if the streams traveled radially, all atoms would have to bypass the earth. In other words, the situation represented by flocculi A and C in figure 6 would be realized.

Further, we know that geomagnetic disturbances are observed immediately after a solar activity minimum, and there are grounds for considering that some of these disturbances are caused by flocculi. The author [4] has come to the conclusion that flocculi located at high heliographic latitudes can be a source of geoeffective corpuscular streams. In this case, obviously, it should be considered that as before there is a radial flux of atoms from the flocculi, but that the atoms are deflected by the magnetic field of the adjacent sunspots or by other local fields, whose presence on the sun has recently been established. If this deflection is such that by chance the stream is directed toward the earth (figure 7), geomagnetic disturbances will be observed. Since the configuration of the sunspots in a flocculus and the structure of the magnetic fields in a group of spots can be different in every case, the nature of the deflection of the corpuscular stream from a flocculus can also differ. In other words, the invasion of the earth's atmosphere by

corpuscular streams must also be of a random nature. This, evidently, is the reason for the failure of numerous attempts to relate geomagnetic disturbances to the passage of sunspots and flocculi across the sun's central meridian.

Generally, if the spot group is very large, its magnetic field will be very complex. Hence, the deflection of particles ejected from different parts of the flocculus surrounding this group can be very different. This is equivalent to an increase in the solid angle of the stream leaving the flocculus. Possibly this is directly related to regularities shown in figure 2. The larger the spot group, the more complex its magnetic field, the greater the solid angle of the stream and, consequently, the greater the probability of its atoms striking the earth even if the groups are located in high heliographic latitudes. Another factor which increases the probability that these atoms strike the earth is the fact that the area of the flocculus will be the greater, the larger the spot group, since the flocculus surrounds the spot group. Thus, the regularities depicted in figure 2 can be explained satisfactorily if we consider that the flocculi surrounding the spots and not the spots themselves are the sources of the geoactive streams.

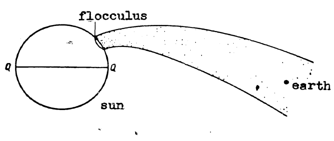

Figure 7. Deflection of streams of corpuscles from flocculi by magnetic fields.

There are still other considerations which strengthen the hypothesis that spots deflect streams coming from flocculi. As has already been mentioned [4], in a number of cases floccular (facular) fields passing across the visible center of the solar disk did not cause geomagnetic disturbances. In practically all these cases, there were spots inside these fields and the author concluded that spots constitute a certain disturbing factor. In deflecting the corpuscles coming from adjacent flocculi, the magnetic fields of spots can make the flocculi crossing the visible center of the solar disk non-geoactive and the flocculi of high latitudes geoactive. Allen's [3] statistical findings infer that spots are a factor which influences the conditions of the departure of corpuscular streams from an active region. Finally, the specific structure of the coronal regions above spot groups ([5], p. 155) attests to the fact that sunspots exert a certain disturbing influence of an electromagnetic nature.

As one of the basic sources of geoactive corpuscles, flocculi satisfy these general laws that have been found from the study of geomagnetic disturbances and other phenomena associated with them. First, the conclusions stated regarding the radial flux of atoms from flocculi agree with the important finding of M. N. Gnevyshev and A. I. Ol' that the solid angle of solar corpuscular streams is very small, about 8-9°, i.e. that particles move almost radially from the sun [6]. Section 5 of our work contains a special discussion of the radiality of solar corpuscular streams. We will see that the most recent data completely confirm this finding, although certain more accurate definitions are needed.

Second, radial streams from flocculi are in agreement with the fact that the 27-day recurrence of geomagnetic disturbances becomes more sharply expressed as one goes from maximum toward minimum solar activity (figure 8). In figure 8a, line ABC is an "edge" projection of the earth's orbit onto the plane of the diagram. In other words, the plane of the ecliptic in figure 8a is perpendicular to the plane of the diagram. The fact that the plane of the solar equator QQ is inclined 7.2° to the plane of the ecliptic is of fundamental importance for what follows. In this case, the earth is at points A and C on 5 March and 7 September. At these times (and close to them), the vector radii drawn from the center of the sun to the earth intersect the sun's surface in

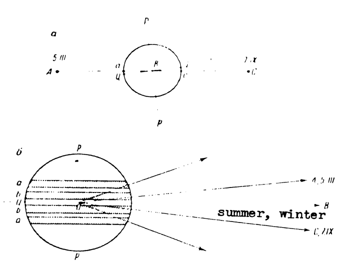

Figure 8. An explanatory drawing of the effect of radiality during the solar activity cycle and also during a year.

the highest heliographic latitudes, at about 7°. In other words, at these times the heliographic latitude of the visible center of the solar disk (points a and c for observers at A and C) is at the maximum possible value, 7.2°. At times 1/4 year removed from the above, the earth is at point B and, correspondingly, at point B', which we can mentally locate at point B but beyond the plane of the diagram. At these times, the vector radii drawn from the sun's center to the earth intersect the sun's surface at the equator, and the heliographic latitude of the visible center of the solar disk is close to zero. However, the heliographic latitude of different formations on the sun changes during the 11-year cycle of solar activity. The mean latitude of spots and flocculi is maximum immediately after a year of minimum and then decreases continuously, being least in years of minimum activity. Thus, at each given moment, these formations occupy a wide belt on the sun. This is all depicted in figure 8b. Belts a and a' correspond to years following immediately after a year of minimum solar activity, belts b and b' are shown for years of minimum activity. QQ is the sun's equator. Spots and flocculi are rarely observed on the equator itself. According to figure 8b, the angle AOC includes the vector radii (drawn from the center of the sun) which are directed toward the earth during the year. Figure 8b shows that the radial streams from belts aa' must bypass the earth (if they are not deflected by the magnetic fields of the spots). As the minimum is approached, more and more frequently the earth comes into radial streams from the sun, i.e., the recurrence of disturbances should become more and more pronounced. It should be noted that the mean latitude of flocculi in years of maximum is near $\pm 15^\circ$, but that quite a few flocculi are observed between $+ 15^\circ$ and $- 15^\circ$ during these years. At these latitudes, flocculi are even observed two years before the solar activity maximum! All this is very important in that it points up the possibility that the examined mechanism is effective for a long period within the solar cycle. It must be mentioned that even at latitudes higher than $\pm 7.2^\circ$, flocculi can cause the recurrence of disturbances. If the configuration of the magnetic fields in a flocculus is sufficiently stable with respect to time, the deflection of corpuscles from the flocculus will remain the same for a number of successive rotations of the sun; hence, if the stream is deflected toward the earth the first time (figure 7), it will be deflected toward the earth in the successive rotations as well!

As follows from figure 8, the radial streams from flocculi explain another important regularity in geomagnetic disturbances, namely the seasonal changes in the behavior of these disturbances. Geomagnetic activity is maximum in spring and fall (around 5 March and 7 September) and is minimum in summer and winter. All this is evident from figure 8b. When the earth is near direction OB, i.e. in summer and winter, the intensity of the corpuscular flux from the equatorial regions (where there are very few flocculi) must be minimum; in fall and spring, however, when the directions are close to OA and OC, it should be maximum.

In conclusion, let us pause briefly on the question of the possible mechanism of the ejection of atoms from flocculi. In a number of works [7 - 10], the author examined the mechanism of ejection of ionized calcium atoms from flocculi and the entrainment of hydrogen atoms by them. Above the flocculi, the selective light pressure (in lines H and K) on the ionized calcium atoms exceeds the gravitational pull and in principle these atoms should leave the sun, carrying with them the other atoms, which are chiefly hydrogen atoms. The following considerations can be cited in favor of this mechanism:

1) the efflux of atoms here should take place from the solar regions where it is actually observed;

2) there is a very real ejection force, namely, light pressure;

3) this mechanism is characterized by radiality of bundles of corpuscles [7], which is also in complete agreement with observations.

On the other hand, there are objections to this mechanism:

1) possible ionization of the calcium ions in the solar corona by electrons of the corona;

2) the resistance of coronal matter to bundles of Ca^+ and H atoms;

3) details of the mechanism of entrainment of hydrogen atoms by calcium atoms, etc. are still unclear.

Means for overcoming these difficulties have been examined by the author in [7-10]. Due to lack of space we will not discuss these questions here, especially since this problem should be solved on the basis of observations, not theory, as the author has indicated in [10]. Finally, and this is the main consideration, the indeterminate nature of the mechanism of the ejection of corpuscles from flocculi has nothing to do with the fact that flocculi are one of the main sources of corpuscular emission and this has been shown by observations.

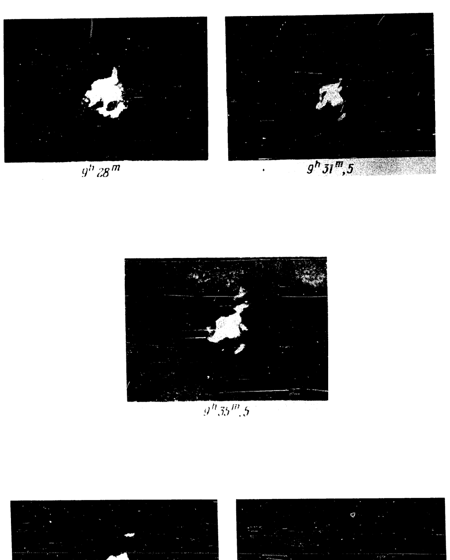

Figure 9.
Chromospheric flare of 26 June 1952.

4. CHROMOSPHERIC FLARES

The name chromospheric flare is usually given to the very rapid (sometimes almost sudden) increase in the brightness of individual sectors of the sun's surface, which is observed most frequently in the lines of the Balmer series and in the H and K lines of ionized calcium but which also appears frequently in some other lines of the solar spectrum. Chromospheric flares are only rarely observed in total light and not in lines, and then for only a short time. Usually a chromospheric flare appears as a sharp intensification of light in some part of an existing bright flare. Chromospheric flares are also closely related to sunspots.

Figure 9 shows photographs of one of the flares taken at the Crimean Astrophysical Observatory [11] in the light of line H_α. Figure 10 shows a photograph of a large chromospheric flare taken by d'Azambuja at Meudon on 25 July 1946.

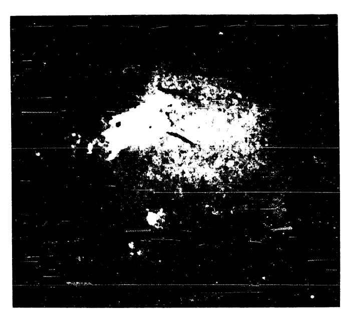

Figure 10.
Large chromospheric flare of 25 July 1946.

The appearance of a quite intense chromospheric flare on the sun is accompanied by poor shortwave radio communication on earth. This is due to the sudden increases in solar ultraviolet (and x-ray) radiation in the region of the flare. This "ultraviolet," purely radiational effect is accompanied by a so-called "hook" on the magnetograms. If the chromospheric flare is intense enough (class 3 or 3+ in a three point system, where 1 is the weakest flare) and is not more than 45° from the center of the solar disk, strong magnetic disturbances of a corpuscular nature and, what is more, disturbances with a sudden beginning are observed on an average 20 hours after the flare [12]. Thus, there is no doubt here that atoms (evidently chiefly hydrogen atoms) are ejected from the region occupied by the flare during the flare up and that these atoms leave the sun with a mean velocity of about 2000 km/sec. On invading the earth's atmosphere, these atoms create disturbances in it. A chromospheric flare is not only the source of atoms moving at a velocity of several thousand kilometers per second, but of corpuscles with considerably higher velocities; in particular, in a number of cases, flares are the source of cosmic rays. Data on solar radio emission for such times attest to the high rate of movement of atoms from flares. V. V. Vitkevich's article gives more details in this respect.

Let us note that corpuscular streams from flares, unlike those from flocculi, are not radial. This is deduced from the fact that geomagnetic disturbances are observed even when a flare is 45° from the center of the solar disk.

Let us recall that chromospheric flares produce storms with a sudden beginning. The mechanism of the ejection of atoms from chromospheric flares has not yet been clarified. First, it would be very interesting to discuss the possibility that the main force might be the light pressure on the hydrogen atoms in the lines of the Lyman series of the flare spectrum. The width and intensity of the L_{α} line must be especially large, as follows from a work by the author and A. B. Severnyi [13], who found that quantitatively for large flares the light pressure is sufficient for the ejection of hydrogem atoms. However, a more detailed examination of the question [14] reveals a number of difficulties in the light pressure hypothesis and the question cannot yet be regarded as settled.

5. THE RADIALITY OF SOLAR CORPUSCULAR STREAMS +)

As was pointed out in section 1 of this article, geophysical laws which reflect the different properties of the streams are one of the basic means of explaining the nature of the solar corpuscular streams. A very important law of this type is the radiality of corpuscular streams, which appears in a considerable number of geomagnetic disturbances but, of course, not in all disturbances, as we saw in the example of chromospheric flares. However, before discussing the question of the radiality of streams, we must state that this is radiality in a very specific sense, viz. in order to maintain radiality, the corpuscles from each point of the active region must move along a radius running from the center of the sun to that point (see figure 11). In figure 11, O is the center of the sun, E the direction to the earth. Only in figure 11a do we have a radial efflux of matter in beams I and I' from the corresponding active regions a and b. In figure 11b, beam II comes to an end along a radius from the center of the sun; however, the efflux of matter from active region c cannot be considered radial. Only streams falling within the dashed lines would be radial. Beam III from region d is even less radial than beam II. These basic definitions of radiality will be kept in mind at all times.

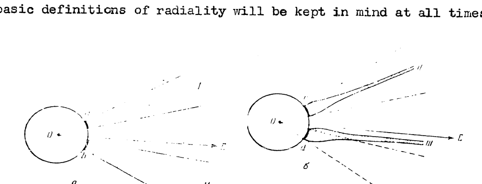

Figure 11.
An explanatory drawing of the idea of radiality of streams.

+) This section was not included in the text of my report at the conference. However, because of the questions which arose on this subject during the many discussions at the conference, the editor of this compendium, on the request of the author, has included it here.

The question of the radiality of corpuscular streams was first examined in detail by M. N. Gnevyshev and A. I. Ol' (/ 6 /, see also / 1 /, pp. 225-230). We will state the main arguments (in our opinion) used by these authors, labeling them A, B and C.

A. The coefficient of correlation between the mean semiannual values of sunspot area in the central zone, with a radius of 6°, and the mean semiannual values of the amplitude of the horizontal component of the magnetic field is considerably larger (by several times) than this same coefficient for the ring zone with an inner radius of 6° and an outer radius of 30°. Figure 8b shows the relationship between this and the radiality of streams.

B. As has already been mentioned in section 3, the equinoctial maxima of geomagnetic activity occur because at that time solar latitudes closest to the zones of maximum solar activity are projected onto the earth. Since the mean latitude of these zones varies during the cycle, as follows from figure 8b, the equinoctial maxima are most sharply expressed in years (close to minimum activity) when solar activity is concentrated in the lowest latitudes. According to M. N. Gnevyshev, this effect actually exists and can be determined quantitatively.

C. Since the mean latitude of active formations on the sun decreases during the transition from maximum to minimum activity, when the streams are radial one would expect that the number of disturbances caused by them would be maximum somewhat after years of maximum solar activity, i.e. maximum geoactivity should lag behind maximum solar activity. Such a lag actually occurs and can be used to determine radiality.

Using all these arguments as their basis, Gnevyshev and Ol' concluded that the solid angle of solar corpuscular streams is approximately $8-9^{\circ}$, i.e. that these streams are practically radial.+)

+) The value $8-9^{\circ}$ is characteristic of the total solid angle. The departures from radiality are $4-4.5^{\circ}$.

The following argument should be added to the three above.

D. If flocculi are a source of geoactive corpuscles, the tendency toward a 27-day recurrence should increase from maximum toward minimum solar activity when the flocculi are already in low latitudes. In other words, when corpuscular streams are radial there must be a close connection between the mean latitude of the flocculi and the percentage of disturbances in the 27-day sequence. According to N. P. Ben'kova / 15 /, this is actually the case. In view of the importance of this result, we have constructed an illustrative graph (figure 12). The solid line (scale on the left) shows the percentage of disturbances with respect to the total number of disturbances for the given period. The dashed line (scale on the right) shows the mean latitude of the spots and, consequently of the flocculi. Figure 12 shows how sharply expressed the radiality of corpuscular streams actually is. It should be mentioned at this point that floccular regions, as opposed to spots, are very stable and last for many rotations of the sun.

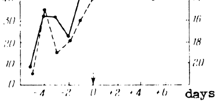

Figure 12. 27-day recurrence of geomagnetic disturbances (solid line) as a function of the mean latitude of spots and faculae (dashed line).

The above conclusions as to the radiality of solar corpuscular streams were arrived at without the benefit of recent data on solar activity. Moreover, a very important circumstance was not considered, viz. that chromospheric flares do not produce radial streams. Hence when disturbances caused by chromospheric flares are separated from the other, the basic, group of geomagnetic disturbances, the radiality of the streams that produce these geomagnetic disturbances should become even more apparent. The new data not only support the conclusion that a large part of the corpuscular streams is radial,

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but they confine these streams even more, bringing them nearer to complete radiality. Let us examine these data.

The last two cycles of solar activity, taken arbitrarily from the maxima of 1937 and 1947, emphasize such manifestations of stream radiality as the increase in the recurrence of disturbances in the years preceding the minimum, and the almost complete disappearance of this recurrence immediately after the minimum.

In figure 13 we show an ordinary 27-day "carpet" of magnetic disturbances for the period May 1942 - January 1946. This graph, sent the author from the Arctic Scientific Research Institue by A. P. Nikol'skii, includes both the disturbances which appeared in the catalogue and the disturbances at Bukhta Tikhaya.+) A moderate storm is indicated by a circle, a large storm by a hollow square and a very large storm by a shaded square. We see that during 1942-1944, two major sequences were observed. The one on the right lasted about a year. There were very few spots in these years. After the minimum, there was practically no recurrence of geomagnetic disturbances. The last solar activity minimum featured a sharp increase in the recurrence of geomagnetic activity. This activity was manifested particularly clearly in 1952 and 1953. It practically disappeared after the minimum and only now, before the maximum, is a recurrence beginning to be manifested, which is in agreement with figure 12. Thus, even without processing the new data quantitatively, it is obvious that the data for the last two cycles should give even a clearer picture of the close connection between the curves of figure 12. Allen [3] divided the recurring disturbances into three types, M, B and E, depending on the position the disturbance occupies in the sequence, namely: an M-disturbance is one which falls within the sequence, a B-disturbance is one which begins a sequence, and an E-disturbance is one which ends a sequence.

+) In approximately 81°N and 52°E [TR.].

Figure 13.
Frequency of geomagnetic disturbances in 1942-1946.

Disturbances which do not occur in the sequence are called T-disturbances. Table 1 gives the distribution of these disturbances for 1906-1942.

Table 1

Period	M	B	E	T
1906-1922	713	151	166	126
1923-1942	977	240	273	154

As Harang [16], Allen [3] and others point out, M-disturbances, like weak polar aurorae, display seasonal variations, with maxima in spring and fall. We give a diagram constructed on the basis of Allen's data [3] as an illustration (figure 14). This diagram shows that the probability of M-disturbances is approximately twice as great in spring and fall as in winter and summer! On the other hand, T-disturbances do not display seasonal variations. These facts can be interpreted only from the point of view that streams which produce M-disturbances (the majority) are radial and that streams which produce T-disturbances are non-radial. Moreover, as we shall see, the relative role of M-disturbances grows from maximum toward minimum solar activity. This is a direct confirmation of argument B.

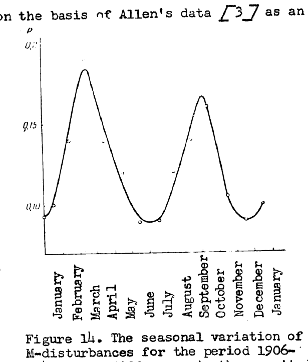

Figure 14. The seasonal variation of M-disturbances for the period 1906-1942. The difference in the magnitude of the equinoctial maxima is caused by asymmetry in the distribution of active regions in the southern and northern hemispheres of the sun for this period.

Newton and Milsom's work [17], based on abundant data for seven cycles of solar activity (September 1878 - May 1952), also classifies disturbances and separates those caused by chromospheric flares.

The authors divide storms into large (G) and small. The small storms are subdivided into storms with a sudden beginning and with a gradual beginning. The curve of distribution of G-storms in the cycle coincides with the mean curve of distribution of very large sunspots and very large chromospheric flares. G-storms are not observed during slight solar activity and, in agreement with the above, are caused by non-radial streams, i.e. streams from regions of very large spot groups situated in high latitudes (deflections of streams by the magnetic fields of spots, see section 3), and also by corpuscular streams from flares.

The distribution of small storms with sudden beginning in the cycle coincides with the curve of distribution of relative numbers of spots in the cycle (figure 15). These storms, possibly, are caused either by weaker chromospheric flares or by still another factor (see below). The tendency toward the 27-day recurrence is almost imperceptible in the case of both G-storms and weak storms with sudden beginning. In the few cases where G-storms recur, there are grounds for assuming [2] that this is related, basically, to the repeated appearance of a chromospheric flare in the same spot group and not to the entry of the earth into the stream of corpuscles which came from the corresponding active region during the previous rotation of the sun.

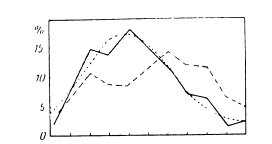

Figure 15. Distribution of the number of storms with gradual and sudden beginning in the solar cycle for seven cycles from September 1878 through May 1952. The mean number of sunspots (dotted line), storms with gradual beginning (420 storms, dashed line), and storms with sudden beginning (235 storms, solid line).

Small storms with gradual beginning are not related to spot groups and have a clearly expressed tendency toward 27-day recurrence. In agreement with section 3, these storms which constitute a large part of the disturbances (essentially, these are M-disturbances, see table 1) are caused by streams from flocculi. The radiality of the given streams is manifested, according to the work cited, in the fact that the maximum number of small storms with gradual beginning is displaced 3-4 years with respect to the sunspot maximum (figure 15). This is in agreement with argument C in [6]. However, in the given case this appears in a still more distinct form, evidently because the disturbances were differentiated in [17]. This very considerable time lag, viz. three-four years, implies the presence of very narrow streams, narrower than those found in [6]. Inasmuch as the main part of the disturbances in years preceding a solar activity minimum are small storms with gradual begining (figure 15), as this period is approached the radiality of the streams becomes expressed especially clearly, which follows directly or indirectly and from many other of the facts examined above.

A. Shapley's work [18], which is specially devoted to the 27-day recurrence of geomagnetic disturbances and which confirms Ben'kova's work [15], gives some very convincing results concerning the radiality of corpuscular streams. Shapley computed the autocorrelative coefficients, which characterize the tendency toward recurrence of disturbances, for the period 1890-1944. He found that the variation of coefficients r_{27}, characterizing the 27-day recurrence of disturbances, +) fluctuates periodically in the solar activity cycle (and in the parallel magnetic activity cycle), but has a phase displacement of approximately 180°. Specifically, the 27-day sequence is very intense during the period which begins approximately two years after the solar activity maximum and falls off abruptly immediately after the minimum. Figure 16 shows Shapley's graph, where the solid line represents the variation of the r_{27} value and the broken line represents the variation of solar activity with respect to the number of spots. From figure 16 we see that the r_{27} value increases after the solar activity maximum and decreases abruptly after the minimum. Essentially, figure 16 repeats figure 12, except that figure 16 shows a weak minimum r_{27} value in a year of maximum solar activity. If this small minimum is real, it can easily be explained by the fact that in years of maximum solar activity the ratio between the number of T-disturbances and the number of M-disturbances has a sharply expressed maximum (figure 15). Furthermore, we saw that in most cases T-disturbances do not display any recurrence of either seasonality or radiality.

+) In this work it was found that there is no sequence of disturbances other than the 27-day multiple.

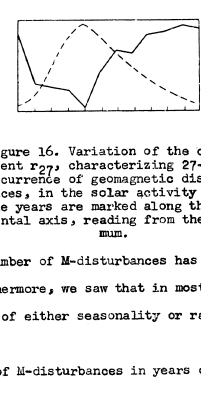

Figure 16. Variation of the coefficient r_{27}, characterizing 27-day recurrence of geomagnetic disturbances, in the solar activity cycle. The years are marked along the horizontal axis, reading from the maximum.

The presence of a certain minimum number of M-disturbances in years of maximum activity (figure 15) can easily be explained by the influence of magnetic fields on sunspots. These magnetic fields may not only deflect corpuscles but may also prevent them from leaving the adjacent floccular fields. This effect is inoperative only when the velocity vectors of the corpuscles and the directions of the lines of magnetic force coincide. Since the configuration of magnetic fields within spots varies during their successive appearances, a disruption of the recurrence of disturbances may occur and obviously this effect must be greatest in a year of maximum solar activity when the role of magnetic fields is maximum. This effect should no longer play an essential role as the minimum is approached, which follows from figure 15 (where the number of M-disturbances again increases after a certain minimum in years of maximum solar activity) and from figure 17, which is taken from [18].

In figure 17, A represents the fluctuation of the r_{27} value for the examined period 1890-1944, B represents the change in the relative number of sun-

Figure 17. Relationship between the coefficient r_{27} and other characteristics of solar and geomagnetic activity.

spots, C the change in μ, which is the measure of magnetic activity and D is the change in the per centum number of sunspots with low latitudes (less than $\pm 10^{o}$).

A comparison of curves A and D in figure 17 is very interesting in the above sense. As Shapely mentions, the trend of both relationships is highly analogous. This similarity lays particular stress on the great role played by the radiality of streams, which is clearly manifest in years of minimum solar activity when active regions (flocculi, from the author's point of view) descend to low latitudes.

Unfortunately, Shapely does not single out the disturbances with sudden beginning; he does not regard them as pertaining to radial streams. If these disturbances had been singled out, the regularities just discussed would have been still more distinct. Undoubtedly, consideration of this factor would have had an effect on the minimum of r_{27} values in figure 16!

A recent work by Chernosky [19] has also confirmed the regularities mentioned above. He, too, found that the tendency toward recurrence of geomagnetic disturbances is less in years of maximum than in years of minimum. Moreover, he arrived at another interesting result. From what has been stated, it follows that the center of activity on the sun moves from minimum through maximum toward minimum within the cycle, toward ever lower latitudes. Moreover, it is known that the angular velocity of rotation of the sun's surface is a function of latitude, decreasing with increasing latitude. Hence, we can expect that the interval between successive recurrences of disturbances must decrease going from minimum through maximum toward minimum. This is confirmed by Chernosky in [19]. The period of recurrence appears to vary be-

tween 28 1/2 days and 26 3/4 days.

Let us summarize what has been said in this section.

1. In most cases, solar corpuscular streams are radial. The following facts attest to this:

a) The seasonal variation of geomagnetic disturbances has two equinoctial maxima. Here the radiality of streams is confirmed by the presence of both maxima and also by the fact that these maxima are most clearly expressed in years of minimum solar activity. This fact is confirmed by the results stated at the beginning of this section (argument B) and also by the fact that the equinoctial maxima are clearly expressed only in M-disturbances [3, 16]. Further, the role of these disturbances increases toward the solar activity minimum and generally their maximum lags three-four years behind the maximum solar activity [17];

b) the increased geoactivity of the low heliographic latitudes. Here we have in mind, first of all, the lag of the M-disturbances (the majority) behind the solar activity maximum (see the beginning of this section, argument C and also the results arrived at in [17]). Second, there is the increased geoactivity of the low latitudes, which is confirmed by the results stated at the beginning of this section in argument A;

c) the increase in the recurrence of geomagnetic disturbances from maximum toward minimum activity. This is also closely connected with the preceding. Figure 12 and also A and B in figure 17 attest to the indicated increase in recurrence of disturbances. A comparison of curves A and D in figure 17 shows that these same low latitudes are the determining factor (which is confirmed, in particular, by the radiality of the streams);

d) there is a correspondence between the flocculi which cross the center of the solar disk and geomagnetic disturbances (see [4]).

It is obvious that all four points considered above involve only the

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radiality of streams and cannot be explained by other effects connected, for example, with the fact that the inclination of the sun's polar axis varies with respect to the direction earth-sun. By polar axis here, we mean the solar axis taken in the sense of the magnetic dipole axis.

Further, it should be noted that a part of the streams from the sun is non-radial. The non-radial streams are those from large spot groups and chromospheric flares.+) Moreover, a number of storms are caused by non-radial streams, namely streams with sudden beginning. Evidently, these are basically T-storms (table 1). It should again be emphasized that weak storms with sudden beginning differ sharply from weak storms with gradual beginning as follows:

a) there is a difference in the very nature of the storms [17] and particularly in the nature of their beginning;

b) there is a conspicuous tendency toward a 27-day recurrence of storms with gradual beginning and an almost complete absence of this tendency with storms of sudden beginning. These differences appear particularly clearly in the work of Thellier and Thellier [20]. Figure 18 is a graph taken from their work. We see a sharply expressed recurrence for disturbances with gradual beginning (top curve, where the intervals between the maxima are 27 days) and the complete absence of this recurrence for disturbances with sudden beginning (bottom curve). The top curve was constructed for 328 storms, the bottom for 210 storms. The central maxima on both curves correspond to the disturbances which were taken as the source material for computation of the average data on geomagnetic activity before and after these disturbances;

Figure 18. 27-day recurrence of disturbances with gradual beginning (top) and the absence of such a recurrence in disturbances with sudden beginning (bottom).

+) Besides floccular streams deflected by the magnetic fields of spots.

c) both kinds of storms have different distribution (according to number) in the solar activity cycle (figure 15). Weak storms with sudden beginning are closely connected with spots; storms with gradual beginning are not connected with spots (flocculi).

d) the most intensive of the weak storms are those with sudden beginning.

2. <u>The role of the radiality of corpuscular streams increases considerably from maximum toward minimum solar activity</u>. The following facts attest to this: 1) the increase in the seasonal variations of magnetic activity toward the minimum, 2) for a large number of disturbances, the lag of maximum geomagnetic activity behind maximum solar activity, 3) the increased recurrence of geomagnetic disturbances during this period (figures 12 and A and D in figure 17) et al.

The increase in the role of radiality of the streams from maximum toward minimum activity is caused by: a) the decrease in the number of flares and large spot groups; b) the increase in the ratio of the number of M-disturbances to T-disturbances; c) the decreased role of the magnetic fields of spots (as a deflecting factor) in connection with the decrease in the area of the spot groups and the number of spots; d) the decrease in the mean latitude of the active formations in connection with the radiality of the streams. To avoid misunderstanding, let us note that the recurrence of disturbances in itself does not indicate radiality of streams.

In 1932, Bartels [21] disputed the existence of corpuscular stream radiality. However, at present his critical remarks have lost all value. In revealing the effect of radiality, he used sunspot data for the hemispheres (southern and northern). Further, since the corpuscular beam is so radial, Bartels' method is too crude. Moreover, Bartels did not differentiate between the large chromospheric flares and T-disturbances and thus did not find such a distinct lag of magnetic disturbances behind solar activity as was found in [17]. At present there is no doubt that most corpuscular streams are radial.

6. SOLAR PROMINENCES

Gaseous formations of different form situated above the chromosphere in the solar corona are called prominences. On an average, prominences are 100 times denser than the corona surrounding them, but their kinetic temperature is approximately 100 times less than that of the corona and is close to that of the chromosphere. Prominences are very complex formations, forming a number of classes. First let us note that prominences of the sunspot class, associated with sunspots, cannot be a source of corpuscles. They are formed in the coronal area and the luminous matter is directed from there down toward the sun.

Eruptive prominences are particularly interesting. Figure 19 shows a photograph of such a prominence, taken by A. B. Severnyi at the Crimean Astrophysical Observatory of the Academy of Sciences of the U.S.S.R. Eruptive prominences are sometimes expelled from the sun at such velocities that they are completely ejected from it. However, such instances are fairly rare, being observed not more than once a year (on the average, per cycle [9]).

The quiescent prominences are the most stable type. In projection onto the disk, quiescent prominences appear as dark bands in the light of some spectral lines. They can be seen clearly in figure 5a. When projected onto the disk, prominences are usually called filaments.

As their name indicates, quiescent prominences in themselves are quite stationary. Nevertheless, Kiepenheuer [22] thinks that there is a definite connection between filaments and M-disturbances. Kiepenheuer's conclusion is based on very meager statistical data, however, and cannot be considered seriously.+)

+) Recently direct proof has been given of the untenability of Kiepenheuer's conclusion [35, 36].

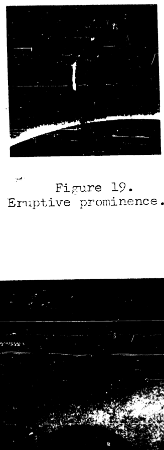

Figure 19.
Eruptive prominence.

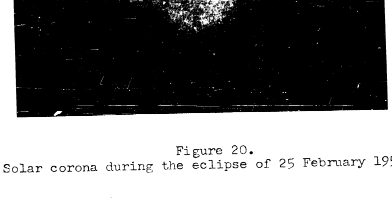

Figure 20.
Solar corona during the eclipse of 25 February 1952.

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It should be noted that the mean latitude of quiescent prominences (and, consequently, of filaments) is approximately 10° greater than that of flocculi and spots, for the same time. Moreover, the latitudinal zone in which prominences are located is very large. Therefore, in the case of quiescent prominences we would not be able to notice the manifestations of stream radiality which are actually observed in geomagnetic disturbances, especially in years before the solar activity minimum. Finally, the mechanism of the emission of matter from prominences is quite unclear from the physical point of view. Recently, Kiepenheuer connected the relationship he found between geomagnetic disturbances and prominences with the hypothesis that corpuscular streams are nothing more than coronal rays. We will examine this hypothesis in the following section.

7. THE SOLAR CORONA

Recently, the idea has been widely circulated that the solar corona itself is a possible source of geoactive corpuscles. In particular, it is assumed that extended coronal rays, at the base of which quiescent prominences are usually located, are the corpuscular streams which produce various effects in the upper layers of the earth's atmosphere (geomagnetic disturbances, etc.) as they approach the earth. The mechanism of corpuscular emission is held to be as follows: atoms at the base of the rays are accelerated (by forces which are still unexplained) in the outer parts of the rays and, assuming velocities of the order of 1000 km/sec, leave the sphere of solar influence. In the Soviet Union, these concepts are being developed essentially in Kiev by S. K. Vsekhsviatskii, G. M. Nikol'skii and E. A. Ponomarev. We are attending lectures on this subject at the present conference. These ideas are also being developed abroad by a number of authors [3, 23].

Figure 20 shows a photograph of the corona during the eclipse of 25 February 1952. Three rays are visible on this photograph.

As has been mentioned, the ideas which form the basis for these concepts will be treated in special papers; thus, we will leave the detailed examination of this question to the pertinent works and make only brief critical remarks at this point. The author assumes that this hypothesis faces a number of difficulties, the chief among which are the following.

In section 5 of this paper we saw that most of the corpuscular streams are radial and that the role of radial streams increases considerably from maximum toward minimum solar activity. This is in complete contradiction with what we know of the corona. According to the most extensive and complete study of coronal forms, made by E. Ia. Bugoslavskaia [5], the angle i between the axis of the coronal helmets (the lower parts of the rays) and the radial direction increases (!) from maximum toward minimum solar activity. In other words, departures from radiality increase[+)] at this time while the radiality of geoactive corpuscular streams increases. Figure 21, taken from Bugoslavskaia's work, shows the relationship between angle i and the phase of solar activity. The triangles indicate the times of maximum solar activity, the circles the minimum. We see, in particular, that angle i is very great, about 20-30°, near solar activity minima (when the geoactive corpuscular streams are

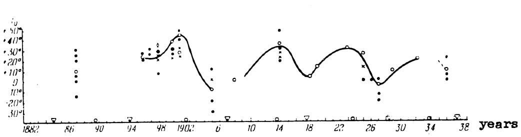

Figure 21. Slopes of helmets and fans in the corona in relation to solar activity.

almost completely radial). This angle is close to zero near solar activity maxima. However, at these times the main, rather extended, coronal rays are

+) This is connected with the general changes in form of the solar corona during the solar cycle.

situated basically at high latitudes, so that the directions of the coronal rays pass at great angular distances from the earth. At slight heliographic latitudes, all coronal formations are smaller. To make this clearer, we show Wesley's [24] diagrams (figure 22) made from photographs of the solar corona during the eclipses of 1900, 1901 and 1905. The eclipse of 1900 (figure 22, 1) was observed the year before a solar activity minimum; the eclipse of 1901 (figure 22, 2) occurred during a solar activity minimum; the eclipse of 1905 (figure 22, 3) approximately coincided with a solar activity maximum. Figure 22 shows clearly that the manifestation of coronal-ray radiality is opposite in phase to that of corpuscular streams! In general, there was absolutely no radiality (established on the basis of geophysical data for years of minimum) of corpuscular streams in the corona during these years. Thus, the above facts provide a convincing argument that we cannot identify corpuscular streams with coronal rays. However, since the problem is controversial, we will make a number of additional remarks.

First, angle i, shown in figure 21, is a mean value. Further, as Bugoslavskaia ([5], p. 168) points out, various helmets in a single corona can have slopes that differ from each other considerably, as is clear from her table 26. For example, the i angles of different rays of the corona during the 1887 eclipse were: -15°; 0°; $+5^\circ$; 0°; $+30^\circ$; $+25^\circ$. For the eclipse of 1941, the i angles were: 0°; $+25^\circ$; $+10^\circ$; $+15^\circ$; 0°; 0°; $+28^\circ$; $+12^\circ$. For the eclipse of 1945, the angles were: $+35^\circ$; $+3^\circ$; $+40^\circ$; $+40^\circ$; $+25^\circ$. Further, the regularities examined in section 5 attest to the almost complete radiality of corpuscular streams, particularly in years of minimum. Departures from radiality, on an average, should not exceed 2-3°, hence it is clear that the coronal rays, with slopes that differ by tens of degrees, could not yield any of the regularities mentioned in section 5, to say nothing of the fact that these regularities are in irreconcilable conflict with the data of figures 21 and 22!

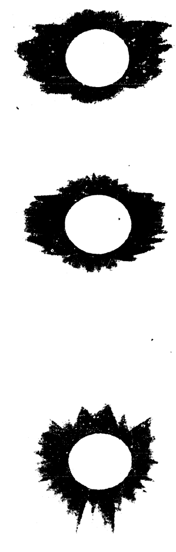

Figure 22.
Diagrams from photographs taken during the eclipses of 1900, 1901 and 1905.

This case, which, to a considerable extent, shows the randomness of distribution of the rays by directions again emphsizes the non-radiality of coronal rays. The form of the coronal rays also indicates their non-radiality. In section 5 we mentioned that corpuscular stream radiality(determined from an immense amount of geomagnetic and solar data) should be taken in the sense of figure 11a. Coronal rays have forms II and III of figure 11b.

Before going on to the next remark, let us note the following. In section 5 we presented a number of facts and concepts which, taken together, harmoniously attest to the existence of radiality in a large number of corpuscular streams, but some of these facts, taken separately, could be used to justify the coronal hypothesis of corpuscular streams. However, obviously such a method is in no way justified. Furthermore, it can be predicted that such an approach will get the hypothesis itself into difficulties. We will cite an example, showing beforehand that it is of general value.

We used the following facts, among others, to evince the radiality of streams: a) the shift of the curve of the number of M-disturbances with respect to the curve of the relative number of spots; b) the increase in recurrence of M-disturbances toward a solar activity minimum.

It could be assumed that these facts are connected with the fact that during the transition from maximum to minimum solar activity the coronal rays are more frequently directed toward the equator and consequently increase the probability that the earth will enter the corpuscular streams, viz. coronal rays (figure 22). However, such an assumption leads to a very serious difficulty. From what has been said in section 5, it follows that the recurrence of magnetic disturbances should decrease sharply immediately after a year of minimum solar activity. This is illustrated, e.g. in figures 12 and 16. This decrease is even of a discontinuous nature (a jump). From figure 13, where 1944 is the year of minimum, one may also draw conclusions as to how rapidly

the 27-day recurrence of geomagnetic disturbances is disrupted. The recurrence of disturbances had almost completely stopped by the middle of 1944. Further, the number of disturbances decreased sharply (which is also a kind of regularity). Consequently, even without resorting to the radiality of streams, we can confirm that sharp variations occur in the geometry and number of corpuscular streams immediately after a solar activity minimum, during a very short period of time when high-latitude spots replace low-latitude spots. However, we did not observe anything similar to this in the corona! The changes in the shape of the corona immediately after a solar activity minimum take place smoothly. Thus, during the eclipse of 21 August 1914, when spots were observed up to a latitude of 30°, the corona had a typical form in minimum [5]. During the eclipse of 24 January 1925, the coronal rays were of the minimum type [5]. This eclipse was observed approximately two years after the solar activity minimum. The shape of the solar corona of 9 July 1945 was also close to the minimum type and was elongated along the equator [5]. Further, from figure 13 we see that the situation in mid-1945 differed from that observed from the beginning of 1943 to April 1944.

In general, immediately after the minimum (in the years the indicated eclipses were observed) the shape of the corona was practically the same as that shown in figures 22,1 and 22,2. In other words, sharp changes in the geometry and intensity of the corpuscular rays in the examined period are in no way connected with the relatively slow changes characteristic of the corona for this period. This is still another serious argument against the coronal hypothesis of corpuscular streams, perhaps even stronger than all the others mentioned above. And a final remark. As a rule, there are quiescent prominences (or, on the disk, filamnets) at the base of the coronal rays (at the base of the helmets). Moreover, it is known that filaments, i.e. prominences, "avoid" active regions with flocculi and spots. Thus, a connection between

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flocculi and corpuscular disturbances practically excludes the possibility of a connection between coronal rays and geoactive streams.

In view of what has been stated above, the author considers the hypothesis which identifies coronal rays with corpuscular-streams to be in sharp contradiction with the facts found on the basis of geophysical data and, therefore, to be incorrect.

8. DISCUSSION OF OTHER POSSIBLE SOURCES OF CORPUSCLES

In this section we will examine other possible sources of corpuscular emission from the sun.

1. The thermal dissipation of atoms from the sun. The solar corona has a very high kinetic temperature, and a number of atoms and electrons, with rather high velocities corresponding to extreme Maxwellian distribution, can leave the sun irretrievably. This mechanism of the "ejection" of atoms from the sun should act continuously and in all directions. However, the very fact that the earth's magnetic field is quiescent between disturbances indicates that this mechanism is not effective [10].

2. Streams of neutrons from the sun. V. A. Petukhov [25] has studied the possibility that the corpuscles ejected from the sun are neutrons which subsequently break up into protons, electrons and neutrons. However, for the present the development of this theory has been too general in form. From the physical point of view in particular, it is unclear why the sun should emit such a large number of neutrons.+) Moreover, the radiality of corpuscular streams is completely incomprehensible from the viewpoint of the neutron hypothesis.

3. Corpuscular streams that create T-disturbances. We saw that some of

+) This question is also discussed in [25].

the weak magnetic storms (the smaller part) are characterized by a sudden beginning and no recurrence. The curve of variation of the number of T-storms within the eleven-year cycle practically coincides with the curve of variation of the relative number of sunspots [17]. However, for the present it is still difficult to say with what the streams (undoubtedly, non-radial) which cause the investigated T-disturbances could be connected. In particular, because of the closeness of these curves, it is difficult to assume that the T-disturbances are caused by coronal rays. The number of sunspots after a minimum increases rapidly and the number of T-disturbances increases with equal rapidity. According to figure 15, two years after the solar activity minimum, the number of weak geomagnetic storms with sudden beginning increases by more than five times. Furthermore, as we saw in the preceding section, for one-two years after the minimum no significant variations were observed in the number of rays in the corona or in their direction.

The close connection between T-disturbances and spots suggests that these disturbances could be associated with chromospheric flares of class 2-3, the more so since the magnetic storms connected with strong chromospheric flares also have a sudden beginning. Further, let us note that of the weak geomagnetic storms, those with sudden beginning are the strongest (relatively). From this point of view, it should be assumed that weak chromospheric flares (class 1) cannot generally create corpuscular streams. Newton's work [2], and in particular figure 2c of this work, shows that class 3 flares, possibly even class 2 flares, can be a source of T-disturbances. Newton finds that the spot groups within which chromospheric flares frequently occur, should be the most geoactive. Allen's work [3] also indicates that flares, at least class 3 flares, may cause geomagnetic disturbances.

However, another possible interpretation of T-disturbances must be kept in mind. In a work which will be presented at this conference, A. B. Severnyi examines the very interesting spectroscopic phenomena, characterized by the appearance in some lines of the solar spectrum of emission which is shifted from the normal position of these lines. Basically, these phenomena are observed in active regions of the sun. If this emission is most intense in sunspot locations, it may explain the origin of T-disturbances as well. It should also be noted that if in this case the origin of the emission is connected with phenomena of an "explosive" nature, the initial velocities communicated to the matter during such explosions must be quite large, of the order of 2000-2500 km/sec. Let us recall that the parabolic velocity on the sun's surface is 617 km/sec.

All these possibilities of explaining weak disturbances with sudden beginning should be studied attentively. In any case, these disturbances differ in many ways from the remaining M-disturbances and thus can hardly be connected with flocculi.

The following fact is very important for explaining T-disturbances. From figure 15, it is obvious that the minimum number of T-disturbances occurring during years of maximum solar activity is considerably less distinct than the corresponding minimum for the number of M-disturbances. In other words, the influence of magnetic fields on streams of corpuscles that create T-disturbances is evidently far smaller (see section 5) than the influence of these fields on the streams that form M-disturbances.

Study of all possible mechanisms of the ejection of atoms from the sun must be continued. In particular, a more detailed study, based on observations, must be devoted to the mechanism of calcium atom emission from the sun due to selective light pressure (section 3). We indicated that in flocculi, the operation of this mechanism must be connected with the fact that the light pressure on the Ca^+ atoms above the flocculi exceeds gravitation. However, E. Milne [26] noted that Ca^+ atoms can be ejected from the sun because of light

pressure if, at the initial moment, these atoms have some very small velocity, of the order of 10-20 km/sec. It is quite possible [7] that from time to time in a number of places on the sun's surface small clots of matter are ejected at low velocities. The total amount of matter ejected in this manner may prove inadequate to create the observed moving details, but it may lead to the effective emission of calcium atoms.

9. THE VELOCITIES OF ATOMS IN STREAMS

The velocities of atoms in streams have not been discussed to any great extent in literature, but this is a very important question for the physics of corpuscular streams, in particular for the quantitative explanation of the different effects which appear in the upper layers of the earth's atmosphere (magnetic and ionospheric disturbances, etc.). Let us examine different methods of determining the velocities of corpuscles and the corresponding quantitative data.

One of the methods most frequently used involves determination of the lag time of geomagnetic (and other) disturbances behind the corresponding solar phenomena. Here, a clear line must be drawn between two cases. In the case of chromospheric flares, we observe the solar phenomenon directly and, on an average, the disturbances on earth can be detected 24 hours after the appearance of the flare. Hence, in this case the earth meets the forward edge of the stream (figure 23a) at the moment the disturbances begin. However, in the case of the most frequently observed disturbances, i.e. the M-disturbances, which tend to recur, we should assume that corpuscles are being ejected continuously, very frequently during many rotations of the sun, from some active region (in the author's opinion, from a flocculus). On entering the stream every 27 days (due to the sun's rotation), the earth (i.e. the upper layers of the earth's atmosphere) is exposed to a corresponding influence from the sun.

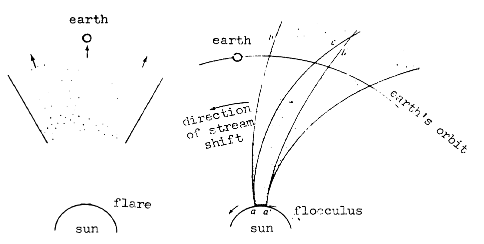

Figure 23. Determination of the lag of geomagnetic disturbances.

Due to the rotation of the sun, the stream in space has the from depicted in figure 23b, where aa' is the active region. Stream abb'a' corresponds to one velocity of corpuscular emission from the active region, acc'a' to another, smaller velocity. To determine the radial ejection of solar corpuscles, Chapman [27] calculated the time interval Δt between the moment the active region+) crosses the central solar meridian and the moment the earth enters the stream. Table 2 was taken from this work.

Table 2

v (km/sec)	100	500	1000	1600	5000
Δt (days)	18.7	9.3	1.9	1.2	1.0

From the data of table 2 it is obvious that even in the case of rather large velocities, viz. 500 km/sec, the time lag is great, more than 9 days.

In the light of these general remarks, let us examine the available data. These data attest to the fact that the mean velocity of movement of atoms in

+) It is assumed that the active region is small. If it is large, the forward edge (according to the rotation of the sun) of the active region is assumed to cross the central meridian.

streams is dependent, evidently, either on the phase of solar activity or on the size of the solar formations that constitute the streams. First, let us return to figure 2. As we saw in section 2, the mean lag time according to curve A is about 1.5 days and according to curve B about 4 days, but let us remember that curve A corresponds to the largest spots. The value Δt = 1.5 corresponds to approximately 1200 km/sec, while Δt = 4.0 corresponds to about 800 km/sec. A small time lag (of the order of one day) is also obtained for large chromospheric flares that create strong magnetic storms with sudden beginning.

Further, as we know, corpuscular velocities can be judged from the shifting of line H_α in the polar aurorae spectra. For a very large storm with sudden beginning, the maximum velocities [28] were about 3200 km/sec; hence, one might suspect a connection between this storm and a chromospheric flare [8]. The velocity obtained for a moderate storm was considerably less [29], on an average about 700 km/sec, which corresponds to about 5.5 days, according to table 2.

One might try to draw some conclusions on corpuscular velocity through the study of the duration of geomagnetic disturbances. We see from figure 13 that the disturbances which recurred in 1943-44 were of great duration. This fact can scarcely be considered the result of some after-effect in the earth's atmosphere after the earth had passed through the corpuscular beam. Actually, as a rule, even after very strong storms, the earth's magnetic field quickly returns to normal. Further, it is hard to imagine that the long life of the disturbances in the period examined (near a solar activity minimum) was connected with a large solid angle of the corpuscular beams in planes parallel to the sun's equator. We saw that in years of minimum (up to the minimum) the streams were practically radial in the meridional planes. Hence, it is natural to assume that the long duration of the examined disturbances was connected

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with different velocities of the atoms in these streams. In this case, the corpuscular stream is like a wide "fan" bounded, for example in figure 23b, by directions ab and a'c', whereupon it should be assumed that the entire expanse between ab and a'c' is filled with atoms moving at different velocities. The velocities decrease continuously from ab to a'c'. Let us assume that all this is so, and let us assume for the time being that the velocity of the fastest corpuscles in the stream, which determine the beginning of the disturbances, is very great, i.e. that $v = \infty$. Then, considering that these disturbances last up to 10 days, and returning to table 2, we find that the velocity of the slowest particles must be about 500 km/sec, which seems entirely plausible. If we assume, in agreement with what has been said above, that Δt is of the order of 5-6 days for weak disturbances, i.e. that the highest velocity in the stream is of the order of 500 km/sec, we find that the lowest velocities in the stream are 200-300 km/sec.

The passage of flocculi across the visible center of the solar disk also causes great lag times in the beginning of disturbances (up to 10 days), i.e. low velocities of the atoms.

Thus, a number of facts shows that in many instances, particularly near a solar activity minimum, the corpuscular velocities can be very low, of the order of several hundreds of kilometers per second. This conclusion does not contradict the physics of the solar envelope in any way. The hypothesis that the velocities of all corpuscular streams are about 1000 km/sec or more is not well founded and, further, it contradicts a number of facts. Values of 1000-1500 km/sec were first derived from graphs similar to that in figure 2A. However, in view of the new data, the spectrum of corpuscular stream velocities should be extended.

10. CONCENTRATIONS OF ATOMS IN STREAMS

The question of concentrations of atoms in corpuscular streams is very

complex. First, it should be noted that concentrations of atoms (i.e. the number of atoms per cm^3) can differ in different cases. Undoubtedly, atom concentrations in streams coming from large chromospheric flares are several orders of magnitude larger than in streams that produce weak M-storms. Moreover, it must be remembered that the structure of the streams themselves is extremely heterogeneous. They are formed by individual streams and condensations and are separated by considerably less dense intervals. This can be judged, if in no other way, by the fact that geomagnetic disturbances, as a rule, consist of separate abrupt and rapid fluctuations of the field. Attention was drawn to the importance of this finding by A. P. Nikol'skii, who has studied problems connected with this (see, e.g., [1], pp. 237-238). Quite obviously this "floccular" structure of the corpuscular streams is caused by highly irregular structure of the active regions of the sun, from which the corpuscles are emitted. Thus, flocculi and chromospheric flares are an aggregate of separate light small spots, filaments, etc. This case will be dealt with in A. B. Severnyi's paper. Further, it is quite obvious that geomagnetic disturbances, consisting of individual abrupt fluctuations, are determined by the concentration of corpuscles in jets and condensations.

The existing evaluations of the concentration of atoms in streams are discussed in one of my works [10]. We shall enumerate the existing data briefly, mentioning the concentrations at the distance sun-earth. We shall not discuss the corpuscular concentrations near the sun. Furthermore, the corpuscles will be studied up to their entrance into the earth's magnetic field which has a focusing effect on the corpuscles, so that the concentration of corpuscles in the upper layers of the earth's atmosphere may be considerably higher than before their entrance into the sphere of influence of the earth's magnetic field.

We have the following methods for estimating the concentrations of solar corpuscles:

1. Calculation of the concentration of corpuscles from the intensity of geomagnetic disturbances. Such estimations assume the presence of some developed mechanism which explains the magnetic disturbance phenomenon. At present we have the well developed and physically probable theory of the initial phase of geomagnetic disturbances (for the principles involved, see [30], p. 430). This theory yields the following results in our case. Chapman [31] finds that the concentration of protons in a stream up to its entrance into the earth's magnetic field (for velocities of the order of 1000 km/sec), corresponding to moderate and large geomagnetic disturbances, falls within the interval 1 to 100 cm^{-3}. Ferraro [32] finds that at this velocity the concentration of protons is between 25 cm^{-3} for large storms and 1 cm^{-3} for smaller storms.

2. Determination of the concentration of corpuscles by the intensity of the displaced H_α line in the polar aurorae spectrum. This theory, developed by I. S. Shklovskii [33], gives the number of protons in the interval sun-earth as 0.7 cm^{-3}. Chamberlain's calculations [34], made in a somewhat different manner, give a concentration of 0.2 protons/cm^3 for moderate polar aurorae.

Of course, these calculations involve a number of uncertainties, but they can hardly contain any serious error. They all indicate that for moderate geomagnetic disturbances (and polar aurorae) the number of protons in the stream at the earth is of the order of 1 cm^{-3}, and for strong disturbances from 25-100 cm^{-3}.

A number of authors dispute the accuracy of these figures because certain phenomena which occur in comets and in the polarization of zodiacal light require considerably higher concentrations (two-four orders of magnitude higher). However, I feel that these situations are still too indefinite to take such

objections seriously. In particular, there is no basis for assuming that the polarization of zodiacal light is caused by electrons alone.+) The polarization of sunlight, diffused by dust particles in interplanetary space, can play a large role. Furthermore, it is not at all clear why these electrons (if the conclusions drawn from the polarization phenomenon are true) must be expelled from the sun, together with an equal number of protons, at "geophysical" velocities of the order of 1000 km/sec. Rather, it should be assumed that we are dealing here with a "quasi-stationary" medium, which, of course, has velocities characteristic of an interplanetary and interstellar medium, i.e. velocities of the order of several kilometers per second or, in the extreme case, of several tens of kilometers per second. Decidedly, there are no bases here for concluding that these electrons and protons are expelled from the sun at velocities of the order of 1000 km/sec! The situation with regard to comets is also uncertain.

Undoubtedly, the question of the concentration of corpuscles in streams will be touched upon in a number of papers. Therefore we will not dwell on it in more detail here.

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QUESTIONS AND ANSWERS

The authors were given the opportunity of revising the text of their answers for print; however, the editors felt it was better not to change the answers to the questions, though they were not always exhaustive.

M. N. Gnevyshev: What evidence is there that streams from eruptions (chromospheric flares) have a large solid angle?

E. R. Mustel': There is evidence in the fact that disturbances of a corpuscular nature are also observed when a large chromospheric flare is at a

+) Electrons are considered to be a component part of corpuscular streams.

distance up to 45° from the center of the disk.

D. Ia. Martynov: Can we be certain that a prominence is a movement of matter and not the effect of illumination?

Mustel': Yes, usually we can tell this because lines in the spectra of moving prominences are displaced correspondingly.

S. K. Vsekhsviatskii: In your paper it was noted that corpuscular emission from high-latitude flocculi is deflected by fields of sunspots. Why is such deflection not recognized in low-latitude streams?

Mustel': This was discussed in the introductory lecture. As one might think, this appears in the fact that during years of minimum there are far fewer spots in floccular fields and the area of these spots is considerably less than in years of maximum. Thus the role of magnetic fields as deflecting factors is considerably less in years of minimum than in years of maximum. For a year or two before a solar activity minimum, when M-disturbances are very frequent, no spots are observed in flocculi sometimes for months.

Vsekhsviatskii: How do you visualize the passage of corpuscular streams through the corona?

Mustel': In order to explain the situation here, let us return to chromospheric flares. It is known that chromospheric flares, usually situated in chromospheric layers or slightly above them (sometimes lower also) are a good source of corpuscles. These corpuscles, clearly not of coronal origin, pass through the corona at velocities of the order of several thousands of kilometers per second, during which they travel in a very broad stream, with a total span of as much as 90°. Thus, this fact indicates the possibility that corpuscles pass through the corona. True, it could be assumed that these corpuscles "draw after them" the entire corona inside a solid angle with a span of 90°. However, non-eclipse observations of the corona and data on eclipses made over a number of years give decisive evidence against such de-

formations in the corona.

Consequently, the structure of the solar corona is such that it allows corpuscles to pass through it from below. I have examined this property of the corona before (Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 3: 3, 1948) in connection with the question of the possibility that calcium ions pass through the corona. In this work I indicated that the heterogenity of the corona is such that the corpuscles could pass through the intervals between the individual ray systems and condensations. Recently new facts, which I have presented in another work (Astronomicheskii Zhurnal, 32: 177, 1955), have appeared on the presence of considerable heterogeneities in the corona. In these works there is a discussion of the question of the effect of matter on foreign atoms passing through the corona.

Vsekhsviatskii: Where was the information obtained that 27-day recurrence appears only (as the author indicated) in epochs before the minimum?

Mustel': I maintained only that this recurrence is maximum in years of minimum. The data on this is given in the introductory report.

G. M. Nikol'skii: The radiality and narrowness of streams was obtained from observations of spots, but the spots themselves are not geoactive. How was the role of the spots distinguished?

Mustel': First, the radiality of streams follows not only from observations of spots. Second, it is known that the laws of latitudinal distribution of spots and faculae on the disk (except for polar faculae) are practically identical. Consequently, we can assume that the regularities found, reflecting radiality, also pertain to faculae (flocculi). A quite different law will apply to prominences.

E. A. Ponomarev: The general magnetic field also exists in the equatorial regions. How do corpuscular streams pass through it?

Mustel': Naturally here it is a matter of determining those forces which lead to the ejection of corpuscles. However these estimates yield very little, because we do not know the intensity of the general magnetic field at the equator. We know only that it is considerably less than at the poles, where it is of the order of one or several oersteds.

L. I. Dorman: What information on the electromagnetic fields in streams do observations give?

Mustel': At present our information on streams is very indefinite, Therefore it is very difficult to give an answer to this question.

LITERATURE CITED

1. Eigenson, M. S., M. N. Gnevyshev, A. I. Ol', B. M. Rubashev. Solnechnaia aktivnost' i ee zemnye proiavleniia (Solar activity and its terrestrial manifestations), Moscow, Gostekhizdat, 1948.

2. Newton, H. Royal Astronomical Society, Monthly Notices, Geophysical Supplement, 5: 321, 1948.

3. Allen, C. Royal Astronomical Society, Monthly Notices, 104: 13, 1944.

4. Mustel', E. R. Akademiia Nauk SSSR, Doklady, 42: 117, 1944.

5. Bugoslavskaia, E. Ia. Gosudarstvennyi astronomicheskii institut im. Shternberga, Trudy, vol. 19, 1949.

6. Gnevyshev, M. N. and A. I. Ol'. Astronomicheskii Zhurnal, 22:151, 1945; also Terrestrial Magnetism and Atmospheric Electricity, 51:163, 1946.

7. Mustel', E. R. Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 3:3, 1948.

8. Mustel', E. R. Akademiia Nauk SSSR, Doklady, 81:363, 1951.

9. Mustel', E. R. Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 10:143, 1953; also Societe Royale des Sciences de Liege, Memoires, Serie 4, 13(3): 223, 1953.

10. Mustel', E. R. Astronomicheskii Zhurnal, 32:177, 1955.

11. Severnyi, A. B. and E. F. Shaposhnikova. Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 12:3, 1954.

12. Newton, H. Royal Astronomical Society, Monthly Notices, 103:244, 1943.

13. Mustel', E. R. and A. B. Severnyi. Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 8:19, 1952.

14. Mustel', E. R. Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 15:95, 1955.

15. Ben'kova, N. P. Gidrometeorologicheskaia sluzhba, Nauchno-issledovatel'skie uchrezhdeniia, Trudy, series 6, issue 2; also Terrestrial Magnetism and Atmospheric Electricity, 47:147, 1942.

16. Harang, L. The aurorae, New York, John Wiley and Sons, 1951. 166 pp. p. 15.

17. Newton, H. and A. Milsom. Journal of Geophysical Research, 59:203, 214, 1954.

18. Shapley, A. American Geophysical Union, Transactions, 28:715, 1947.

19. Chernosky, E. American Geophysical Union, Transactions, 32:861, 1951.

20. Thellier, M. E. and Mme. O. Thellier, Academie des Sciences, Paris, Comptes Rendus, 227:1044, 1948.

21. Bartels, J. Terrestrial Magnetism and Atmospheric Electricity, 37:1, 1932.

22. Kiepenheuer, K. Astrophysical Journal, 105:408, 1947.

23. Pecker, J. and W. Roberts, Journal of Geophysical Research, 60:33, 1955.

24. Wesley, W. Royal Society of London, Philosophical Transactions, Series A, 226:363, 1927.

25. Petukhov, V. A. Lecture in the collection Trudy tret'ego soveshchaniia po voprosam kosmogonii (Transactions of the third conference on cosmogony). Moscow, Izdatel'stvo Akademii Nauk SSSR, 1954. p. 210.

26. Milne, E. Royal Astronomical Society, Monthly Notices, 86:459, 1926.

27. Chapman, S. Royal Astronomical Society, Monthly Notices, 89:456, 1929.

28. Meinel, A. Astrophysical Journal, 113:50, 1951.

29. Gartlein, G. Physical Review, 81:463, 1951.

30. Mitra, S. K. Verkhniaia atmosfera (The upper atmosphere). Moscow, Izdatel'stvo inostrannoi literatury, 1955.

31. Chapman, S. Annuales de Geophysique, 8(2), 1952.

32. Ferraro, V. Journal of Geophysical Research, 57:15, 1952.

33. Shklovskii, I. S. Akademiia Nauk SSSR, Leningrad, Krymskaia astrofizicheskaia observatoriia, Izvestiia, 8:51, 1952.

34. Chamberlain, J. Astrophysical Journal, 120:360, 1954.

35. Roberts, W. and D. Trotter. Journal of Atmospheric and Terrestrial Physics, 6:282, 1955.

36. Leighton, H. and D. Billings. Journal of Atmospheric and Terrestrial Physics, 7:349, 1955.

SPECTROSCOPIC INVESTIGATION OF CORPUSCULAR EJECTIONS ON THE SUN

by

A. B. Severnyi

1. INVESTIGATION OF THE PROFILES OF THE H AND K LINES OF IONIZED CALCIUM IN FACULAE

In 1951, V. B. Nikonov and A. B. Severnyi first discovered the characteristic asymmetry of the H and K line profiles in faculae. The electrospectrophotometric method used in this case assured an accuracy which left no doubt as to the reality of the asymmetry effect studied differentially, i.e. by the difference between the residual intensities of these line profiles in the facular spectrum and the corresponding undisturbed disk.

The apparatus for photoelectric recording of the solar spectrum in the solar tower telescope is shown in figure 1.

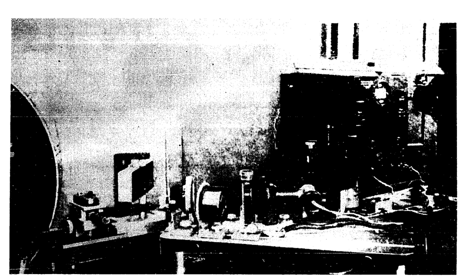

Figure 1. Device for photoelectric recording of the solar spectrum.

The following important improvements were made in this new apparatus:

a) the vignetting of the spectrum, which is caused by the small size of the speculum which "oscillates" the spectrum, was eliminated;

b) various rates of recording the spectrum were used (from 1/4 to 1/500

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cps), which allowed recording without a time lag; and also various time constants were used at the amplifier input and provision was made for rapid and easy change of these time constants;

c) provision was made for a rapid and convenient exchange of one photomultiplier (for the visible spectrum) for the other (for the red and infrared);

d) VEI photomultipliers +) were used with a low noise-to-signal ratio and a small dark current, etc.

Figure 2 shows an example of a recording of the H line in a facular spectrum: in the center one can see a double reversal caused by a flocculus.

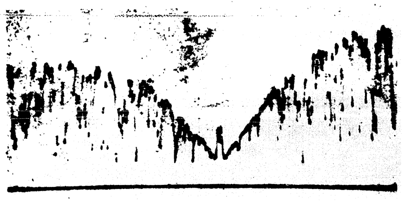

Figure 2. A recording of the H line of a facular spectrum.

Figure 3 shows the distribution of extra "emission" in facula No. 42 for various days: the distances from the center of the H and K lines in Å are plotted along the x-axis, the difference between the residual intensities of the facula and the photosphere is plotted along the y-axis (the dots correspond to the K line, the circles to the H line). The asymmetry of the indicated difference (in the sense "blue wing minus red wing") of extra "emission" in the facula (a unit on the y-axis is equal to the intensity of the continuous

+) Photomultipliers made by the All-Union Electronics Institute (Vsesoiuznyi Elektrotekhnicheskii Institut). [Tr.]

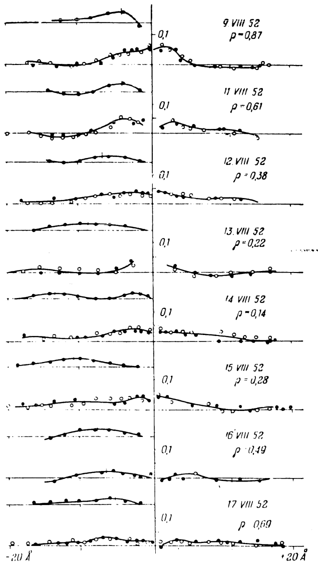

Figure 3.
H and K emission profiles in facula No. 42.

spectrum) is shown in the upper left for each day. Every distribution of extra emission was obtained by averaging the results of 3-9 separate recordings. The mean square error of one individual measurement (according to the records of 1952) is 0.5% ; at present this error has been reduced to 0.25%. The extra emission and its asymmetry were obtained by differentiation; therefore, the measured effect cannot be related to any systematic errors whatsoever, in particular errors of an instrumental nature (e.g., the polarization of light in the instrument and its variation during the recording, et al.).

More than 30 faculae were studied (1952-1954). An examination similar to that shown in figure 3 showed: 1) in practice, the profiles of the extra emission for the H line agree well with the profiles for the K line; 2) in most cases, the blue wing of extra emission is higher than the red wing; 3) the position and magnitude of the extra emission and its asymmetry vary from facula to facula and also, with the passing of time, for the same facula. The position of the asymmetry maximum varies from 300 to 1000 km/sec (if the distances from the center are expressed in velocities), the magnitude of the asymmetry varies from 1 to 5%. In this case, the position and magnitude of the asymmetry do not correlate with the intensity of the H_2, K_2 emission in the center of the line which is produced by a flocculus. Further, except for one case (facula No. 42, given in figure 3), the position and magnitude of asymmetry are not functions of the position of the facula on the disk. In the case of facula No. 42, the position of maximum asymmetry shifted approximately according to the law $\Delta\lambda \sim \cos\theta$ in its passage across the disk; however, the magnitude of this emission did not reveal any relationship to the position of the facula on the disk. Hence, if the investigated asymmetry is connected with radial streams of particles, these streams do not go beyond the limits of the chromosphere, since otherwise the intensity of the blue wing, as compared with that of the red wing, would have increased statistically as the facula approached the center of the disk.

Basically, the observable effect of the extra emission asymmetry is not connected with the possible difference in the behavior of the metallic lines in the facula and in the photosphere, which blend lines H and K, since the disposition of the blends differs in the H region and in the K region and both lines generally give results that are in agreement. Furthermore, the examined effect cannot be connected with the mutual blending of the H and K lines, since (as calculations of the theoretical profiles of these lines have shown, with consideration of their mutual blending) blending can lead to an effect of the opposite sign revealed at distances $\Delta\lambda > 10$ Å and cannot in any way explain such diversity of the profiles of the extra emission. Figure 4 gives the theoretical profiles of the H line for the disk (solid line) and for a facula (dashed line); the theoretical emission profile in the facula is shown below, and its asymmetry is shown on the left.

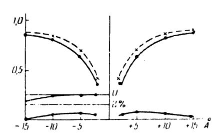

Figure 4. Theoretical profile of the H line.

If the extra emission of the blue wing (asymmetry) is connected with corpuscular streams, its measured magnitude makes it possible to judge the density of the stream of Ca^+ ions, considering that the stream does not extend above the upper chromosphere (otherwise we would observe a relationship between the magnitude of this emission and $\cos\theta$). On an average, the equivalent width of the excess emission ~ 0.1 Å and is concentrated in a column of approximately 40,000 km, so that the emission per unit volume is approximately

$$\frac{2 \cdot 10^6 \cdot 0.1}{4 \cdot 10^9} \simeq 5 \cdot 10^{-5} \text{ erg/cm}^3\text{sec.} \qquad (1)$$

Calculations show that the process of recombinations of a Ca^+ ion to the 4^2P level does not explain such emission. The process of collisions of the Ca^+ ions with electrons explains it more effectively; in this case, for the energy we have

$$Z_c h\nu \simeq q v n_e n(Ca^+);\ h\nu; \qquad (2)$$

when $v \simeq 10^8$ and $q \simeq 10^{-15}$, we get, from (1) and (2):

$$Z_c h\nu \simeq 2 \cdot 10^{-18} n_e n(Ca^+) \simeq 5 \cdot 10^{-5}$$

whence, assuming $n_e \simeq 10^{10}$, we get

$$n(Ca^+) \simeq 10^4 \text{ cm}^{-3}.$$

If we calculate the distribution of n_e on the basis of velocities, the magnitude $n(Ca^+)$ will be still smaller. Thus, spectroscopic data show that corpuscular streams have low density, of the order of 1 cm^{-3} (at the earth's surface).

The asymmetry of the extra emission in the H and K lines of faculae is a

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very real effect, beyond possible errors. One cannot conceive of any sensible physical mechanism for its appearance, except the ejection of corpuscles from the faculae. If this effect is caused by corpuscular streams, they cause illumination only in the low layers of the solar atmosphere, otherwise we would be able to observe them above the chromosphere as well as we do the prominences.

Recently a very interesting spectrogram with K_4 emission above the chromosphere over a facula was obtained on the solar tower telescope. It reached a brilliance of approximately 10% of the continuous spectrum, while its profile was non-turbulent with a half-width of approximately 0.15 Å, corresponding to a purely thermal Doppler broadening, as if this were a stream within which the particles had only a thermal distribution of velocities.

Further evidence of the connection between this effect and corpuscular ejections from faculae is given by the good agreement (80% of the cases) between the precomputed moments of corpuscular disturbances (according to our spectral data) and the actual moment of the magnetic disturbances based on K-index data.

2. INVESTIGATION OF THE PROFILES OF THE H_α LINE IN THE SPECTRUM OF FACULAE

A similar investigation was made for the hydrogen line H_α in the spectrum of faculae. The preliminary results of this investigation also indicate the presence of a clearly expressed asymmetry in the behavior of the difference - faculae minus photosphere - in the H_α line for the same faculae that showed asymmetry in the H and K lines.

Figure 5 shows some typical profiles of this difference (the extra "emission" value, in an algebraic sense, in percents of the continuous spectrum is plotted along the y-axis). In the case of the H_α line in the faculae, too, no

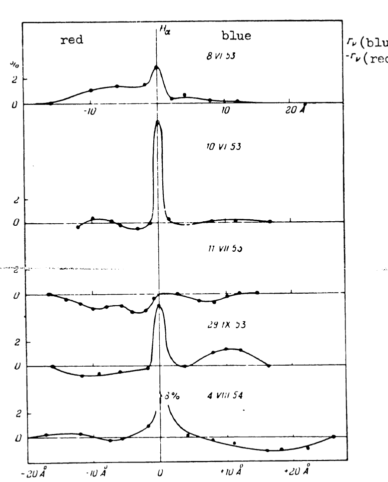


Figure 5. Some typical H_α profiles in faculae.

connection was discovered between the emission in the center of the line and the nature of the asymmetry. Furthermore, no systematic variation of this asymmetry from the center to the edge was discovered.

Most interesting was the comparison of the asymmetry in the H and K lines with the asymmetry in the H_α line for the same faculae. Figure 7 gives the extra (algebraically) emission in the facula for the H_α lines (dots) and the K lines (circles). Analogous graphs were also obtained in other cases.

We see that the distribution of extra emission of the facuale minus the photosphere is quite different for the H_α line and the H and K lines. However,

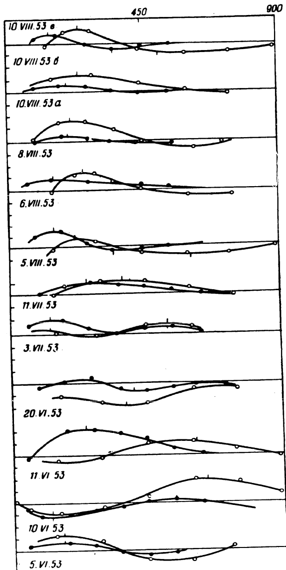


Figure 6. Asymmetry of the K and H_α profiles in faculae.

if we compare the distribution of asymmetry, i.e. the difference r_ν (facula)-r_ν (photosphere) for the red wing minus this same difference for the blue wing instead of the distribution of the differences r_ν (facula)-r_ν (photosphere), we will get an entirely different picture: the distribution of the H_α asymmetry reproduces quite well the distribution of the asymmetry of the K (or H) line and the asymmetry extremes in the K line either agree with those of the H_α line or they are displaced toward higher velocities. Several examples of the comparison of the asymmetry in H_α (dots) and K (circles) are given in figure 6, where a scale of velocities (for comparison) is given along the x-axis instead of a scale of wave lengths.

This comparison shows that the asymmetry effect appears in faculae simultaneously in the H and K lines and in the H_α line, as it should if streams are involved here which contain hydrogen and calcium particles.

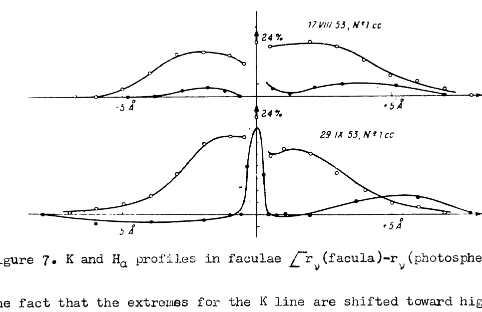


Figure 7. K and H_α profiles in faculae [r_ν(facula)-r_ν(photosphere)].

The fact that the extremes for the K line are shifted toward higher velocities as compared with the extremes for the H_α line shows, possibly, that the velocity of the Ca^+ ions in the stream of particles is greater than the velocity of the hydrogen atoms. At the same time, the conditions for the formation of the H_α and H and K absorption lines in the solar atmosphere are highly varied, which leads one to view this conclusion cautiously: with the same rate of emission of Ca^+ ions and hydrogen atoms, the absorption action in the sphere of the line can exert a special masking effect on the emission and create the appearance of a difference in velocities.

3. THE FINE STRUCTURE OF FACULAE EMISSION ("MUSTACHES")

The new solar tower telescope made it possible to detect recently some very interesting and amazing features of flare and facula emission, viz. the so-called fine structure of this emission and "mustaches." It was found that with good images, the continuous and linear emissions are concentrated in individual "centers" or "grains" no larger than a circle of scattering of 0".4 (~300 km) in some instances.

The emission in the lines differs from the ordinary picture of a diffuse emission reversal and has the appearance of groups of narrow and sharp bright threads intersecting the line. Often one observes only fine, glowing wings, i.e. "mustaches" in absence of any clearly expressed reversal in the nucleus of the line, as if the nucleus remained undisturbed. This phenomenon, evidently, is of the same type as the "hydrogen bomb" observed at one time by Ellerman, however it is much more concentrated and is not associated with a chromospheric flare, as in the case of Ellerman. However, we pay special heed to the fact that here it is primarily only the blue emission wing along the lines of the Balmer series H_α, H_β, ..., and the H and K lines that appears. These mustaches are also observed sometimes in absorption, in which case they are traced to 5 Å along H_α and to 10-12 Å along the H and K lines. Various types of such mustaches are shown in figure 8. These mustaches are a short-term phenomenon, sometimes lasting only a few minutes; it is quite difficult to obtain their spectrum, since a high resolving power and particularly steady images are required.

We are inclined to regard unilateral or asymmetrical mustaches in emission or absorption as spectroscopic evidence of corpuscular streams. The distribution of emission in mustaches is very characteristic, it is much like that shown above for faculae. Figure 9 (top) shows profiles of emission in such mustaches, observed in the chromosphere (dots) and in the neighboring undisturbed photosphere[+)] (circles); in the center is a profile of extra emission in the mustaches, and at the bottom a profile of the asymmetry of this emission (excess of emission in the blue wing as compared with the emission in the red wing).

When photoelectric recording is used, a quite high slit must be chosen in order to eliminate the harmful effect of noises occurring with small light currents. Therefore, in the photoelectric recording of faculae consisting of

+) The original says undisturbed chromosphere [Tr.].

Figure 8.
Various types of mustaches.

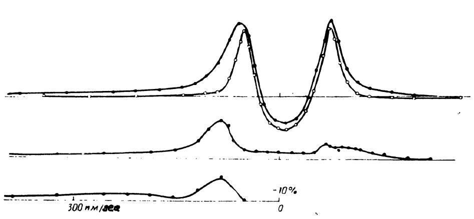


Figure 9. Emission profiles in mustaches.

individual grains with similar mustaches, we must average the whole fine structure and record a mixed profile, formed by the simultaneous action of these grains and the undisturbed photosphere between them. Thus, the observed photoelectric asymmetry of the H_α and the H and K lines is evidently a total "damped" effect of the undisturbed photosphere, an effect produced by the individual emission centers of the mustaches.

An examination of the mustache spectra shows that 1) the streams of particles are concentrated in very small centers, i.e. grains, of the order of several hundred kilometers; 2) the corpuscular ejections are of short duration (sometimes of the order of several minutes); 3) the ejections originate at various depths below the reversing layer,+) primarily at great depths; 4) the mustaches appear at various distances from the center of the disk, in which case the asymmetrical mustaches appear both on the limb and in the center of the disk and sometimes are even observed in the chromosphere (figure 9).

+) The following facts attest to the origin of mustaches at great depths: a) the lines near which they are observed often are shifted as a whole toward the blue, under the mustaches; b) the weak metallic lines at the site of a mustache show the same thing; c) mustaches occur in the far wings of the lines; d) the H_δ line in absorption is sometimes observed above the mustaches.

If the observed asymmetrical mustaches give evidence of corpuscular streams, which is confirmed by the asymmetry of the emission and the shift of the lines as a whole toward the blue, these streams cannot be purely radial. Actually, in the case of purely radial emission we would observe primarily blue mustaches in the center and very small symmetrical mustaches on the limb, (because of the slight dissolution of the corpuscular bundle) or else there would be no mustaches at all. Furthermore, the emission magnitude would show the relationship of the center to the limb, while observations show that the asymmetrical mustaches are as clearly expressed on the limb as in the center, and even more clearly expressed (the blue wing is brighter and more extensive than the red) and the lines on the limb also shift, as a whole, toward the blue. Therefore, the center of corpuscular emission cannot be represented either as a jet always directed radially or as the upward ejection of some superheated "blister," as was proposed recently by E. R. Mustel' when explaining the appearance of the continuous flare spectrum (in the case of a "blister" the lines as a whole would not shift toward the blue at the limb of the disk).

However, the observed features of the asymmetry can be explained satisfactorily if the ejection of particles is conceived of as an explosion, during which the particles fly off in all directions with the same initial velocities. Actually, with a symmetrical explosion: 1) we will always observe approximately the same picture both in the center and on the limb of the solar disk, i.e. there will always be a component of flow along the line of sight; 2) since during a symmetrical explosion the receding particles always (in the center and at the limb) basically go into a region of greater geometric and optical thicknesses in the sphere of the absorption line (while the approaching particles basically go toward lesser thicknesses), the blue wing will be brighter and more extensive in this case than the red wing. Furthermore, the receding particles in an explosion close to the periphery (except, perhaps, for a chance explosion in the chromosphere on the limb will go, basically, into deeper and denser layers, i.e. they will be decelerated more than the particles coming toward the observer and passing through (basically) less dense layers. Therefore, the red wing may be less extensive than the blue. Only in the case of a very rapid lifting of the exact center of the explosion, e.g., would we observe a brighter red wing, whose emission would pass unattenuated through a mass which is moving quickly upward and absorbing, basically, from other frequencies.

It would seem that such a concept of corpuscular ejections does not agree with the concentrated nature of the corpuscles ejected from the sun at a small solid angle. However, if the explosions take place at some depth in the solar atmosphere, the path of penetration of the particles will be greatest in a radial direction, and if the losses to deceleration are approximately $1/v^2$ (v is the velocity of the particles), also the largest number of particles with the greatest velocity will leave in a radial direction, where the losses are least. Thus, if the path of penetration is approximately v^4, such a clear relationship could also cause the outgoing bundle to be narrow. If symmetrical explosions in faculae occur at a depth, the closer the faculae are to the edge, the fewer the particles that will be ejected along the line of sight (due to greater thickness), but all the same some particles may also be ejected along the line of sight in the case of a facula on the limb. Possibly this is associated with the presence of some sort of corpuscular disturbances of the earth's magnetic field also in the case of faculae remote from the visible center of the sun. There is much other evidence, both kinematographic and spectroscopic, to support the hypothesis of an explosive, extremely dissipative process in the emission centers. I have presented this evidence recently [1] and cannot dwell on it at this time.

If the explosion concept is correct, the indication of a Ca^+ ion velocity

greater than that for hydrogen could be an indication of a nuclear explosion in which particles of great mass could have the same velocities as light particles, and even greater velocities. The cross section for very rapid particles is approximately $1/v^4$, and such particles could be comparatively freely accelerated by magnetic fields.

Two years ago we pointed out the possibility of special nuclear processes in the solar and stellar atmospheres in connection with certain peculiarities in the behavior of chromospheric flares [2]. Recently J. Greenstein also concluded that nuclear explosions are possible; he mentioned this in a lecture at the meeting of the International Astronomical Association held in Dublin in September of 1955.

QUESTIONS AND ANSWERS

E. I. Mogilevskii. Was the question of asymmetry in other lines of the solar spectrum investigated?

A. B. Severnyi. No, it was not investigated. To check for possible instrumental causes of the asymmetry, the profiles of some lines (chiefly telluric) were also investigated and they proved to be symmetrical. However, the asymmetry we are dealing with in this work is obtained differentially, and thus cannot be associated in any way with possible instrumental effects.

N. N. Pariiskii. Why do you consider that the mustache phenomenon occurs at considerable depths in the solar atmosphere?

Severnyi. The mustache phenomenon is observed even in the chromosphere, but essentially it is a deep phenomenon, since: 1) in the mustache region, all lines around which the mustaches occur and also some weak metallic lines shift as a whole toward the blue; 2) the mustaches occur far from the line nucleus, in those parts of the wings which form at considerable optical depths 3) the H_ε line in absorption is observed over the mustaches; 4) the mustaches sometimes wash out the weak lines and sometimes do not.

N. A. Iakovkin. If one assumes an explosion, is it possible to calculate the equivalent width of the mustaches?

Severnyi. It is very difficult to do so.

LITERATURE CITED

1. Severnyi, A. B. Akademiia Nauk SSSR, Moscow, Krymskaia Astrofizicheskaia Observatoriia, Izvestiia, vol. 16, 1956; Astronomicheskii Zhurnal, 33(1), 1956.

2. Trudy chetvertogo soveshchaniia po voprosam kosmogonii (Proceedings of the Fourth Conference on Cosmogony), Moscow, Izdatel'stvo Akademii Nauk SSSR, 1955.

SOLAR CORPUSCULAR RADIATION AND THE TOPOLOGY OF THE MAGNETIC FIELD IN THE SOLAR CORONA

by

E. A. Ponomarev

Up to the present time, study of coronal forms has amounted basically to a classification of them according to their external features and to seeking a connection between coronal and chromospheric formations [1, 2]. In this latter case, the basic criterion is the entire complex of "environment."

Two basic elements of coronal structure were identified: the aggregate of fine, slightly bent, rays in the polar regions of the corona, which van de Hulst called polar brushes, and the large coronal rays similar to onions, called helmets or fans.

Van de Hulst [3] proposed that polar brushes are a concentration of the coronal matter flowing along the lines of force of the general magnetic field of the sun. Later, G. M. Nikol'skii [4] pointed out that the distribution of electron density in polar rays and large coronal rays can be explained by the movement of coronal matter from the sun with increasing velocity. S. K. Vsekhsviatskii et al. pointed out [5] that such a conclusion is not in contradiction with spectral observations of the corona. Nikol'skii, however, established that the factor which caused the asymmetry in the structure of the polar brushes of the corona of 30 June 1954 was in the equatorial plane, i.e., it practically coincided with the axis of the large coronal rays. A comparison of the behavior of the average lines of coronal rays with the lines of force of the dipole field showed that this is a systematic departure. The polar rays are more strongly inclined toward the polar axis, and this inclination increases with an increase in polar distance.

The fact that H. D. Babcock and H. W. Babcock [6] discovered a rather stable systematic magnetic field in the polar regions of the sun gives grounds for assuming that polar brushes are actually streams of matter along the lines of force of the general magnetic field of the sun. However, magnetograph observations of the lower layers of the solar atmosphere cannot shed light on the structure of the magnetic field in the outer corona. But, nevertheless, indirect conclusions can be drawn from this.

Kiepenheuer, in 1935, still knew nothing of the general magnetic field of the sun, and simply postulated that it is screened in the corona. He examined [7] a family of trajectories of clouds of ionized gas ejected from the sun's surface and "puncturing" the magnetic field enveloping its surface. In this case the clouds are magnetized and, due to inertia, move further into the gravitational field, and in the magnetic field itself (each cloud of the field is created by the other clouds).

The family of trajectories of these clouds, a function of four parameters, created a picture reminiscent of the form of the corona during various epochs.

Kiepenheuer's theory was artificial, and it would not be worthwhile mentioning were it not the first attempt to explain coronal forms by the movement of a neutral conducting medium in the magnetic field of the sun. At present there is a much sounder basis for such an explanation.

To explain the very existence of coronal rays for some considerable length of time, it must be assumed that at the boundary of the rays there is a magnetic field with intensity 10^{-4}-10^{-5} gauss. Otherwise, a coronal ray would not last even 10 minutes (the coefficient of diffusion of matter in the corona $\sim 10^{17}$ cm^2/sec).

The existence of a general magnetic field of the sun makes it possible to explain the form and lifetime of polar brushes, but at first glance, the magnetic field is only a hindrance in explaining the fan-like forms. However, as we will see later, this is not the case. Before turning to this question, I would like to point out the need for rejecting all attempts to explain the magnetic field enveloping the ray by the existence of an electric current along the ray's axis, since in order to create a field with an intensity 10^{-6} gauss at the boundary of the ray a current is required which would double the charge of the sun in less than a minute.

We should pause here to examine the assumption that the field which "protects" the coronal ray is formed by closed currents in the ray itself. These currents can be induced by an external (with respect to the ray) magnetic field. For this, either the field must be variable, or the conducting matter should move in an external field.

The vorticity fields which create the magnetic "armament" of a ray can appear only as a result of the motion of coronal matter in the sun's general magnetic field. Let us examine the following problem in more detail.

Let us assume that at any place on the limb of the sun (polar distance γ) there is a source of the matter, moving radially in a fine jet. Let us assume that the sun has a dipole field with moment M, where the dipole axis coincides with the polar axis. If the matter has diametrical electrical

conductivity σ_1 and moves with velocity u, in the jet, current

$$j = \frac{\sigma_1}{c}\left[u \times H_0\right] \tag{1}$$

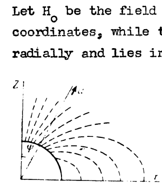
is induced. Under these assumptions, one may find a magnetic field in the solar corona, examining it as the sum of the initial dipole field and the proper field of the ray induced by the movement of conducting matter in this dipole field. When the field is successfully established,

$$\operatorname{rot} h = \frac{4\pi\sigma_1}{c^2}\left[u \times H_0\right], \tag{2}$$

where h is the induced field and H_0 the initial field. For the vector potential we have

$$\Delta a = -\frac{4\pi\sigma_1}{c^2}\left[u \times H_0\right]. \tag{3}$$

Let H_0 be the field of the magnetic dipole located at the origin of the coordinates, while the velocity of the matter in the ray u is directed radially and lies in the plane xz (figure 1). Then (3) has the solution



$$a_y = -\frac{2\pi M}{c^2}\iint_{r'\vartheta} \frac{\sigma_1 u(r',\vartheta)\, r'^2 \sin^2\vartheta\, dr'\, d\vartheta}{r'^3 \sqrt{r'^2 - 2rr'\cos(\vartheta-\varphi) + r^2}}, \tag{4}$$

Figure 1

where M is the magnetic moment of the initial dipole field, ψ is the polar distance of the source of the matter, r' and ϑ are the coordinates of the "sources" of the field, and r and φ are the coordinates of the points of measurement. Let us assume that the density of the current of a number of particles j_n = nu is zero everywhere except for the straight line $\vartheta = \psi$ on which $j_n = \infty$; however, the total current

$$J = \int_0^\pi j_n \cdot d\vartheta$$

is finite, i.e., $u(r'\vartheta) = u(r') \times \delta(\vartheta - \psi)$.

Integrating (4) using the formalism of the δ-function, we get

$$a_y = -\frac{2\pi M}{c^2}\sin^2\psi \int_{r'=R_\odot}^{\infty} \frac{u\sigma_1(r')\, dr'}{r' \sqrt{r'^2 - 2rr'\cos(\psi-\varphi) + r^2}} \tag{5}$$

where $R_\odot$ is the radius of the sun and σ_1 is the conductivity perpendicular

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to the magnetic field. In a strong field,

$$\sigma_1 \sim \frac{1}{nH}, \quad \text{while} \quad u\sigma_1 \sim \frac{r^{\alpha-2}}{T^{3/2}},$$

where α is the r-exponent in the expression for the variations of electron density with distance. Assuming $u\sigma_1$ = const (in the outer corona it increases weakly), let us integrate (5):

$$L_y = \frac{L}{r}\ln\frac{2r}{R_\odot[1-\cos(\psi-\varphi)]}, \tag{6}$$

where

$$L = \frac{2\pi M u\sigma_1}{c^2}\sin^2\psi.$$

Changing from the vector potential to the field intensity, we have

$$\left.\begin{aligned} h_x &= \frac{L}{r^2}\left[\cos\varphi\ln\frac{2r}{R_\odot[1-\cos(\varphi-\psi)]} - \left\{2\cos\varphi - \frac{\cos\varphi-\cos\psi}{1-\cos(\varphi-\psi)}\right\}\right], \\ h_z &= \frac{L}{r^2}\left[\sin\varphi\ln\frac{2r}{R_\odot[1-\cos(\varphi-\psi)]} - \left\{2\sin\varphi - \frac{\sin\varphi-\sin\psi}{[1-\cos(\varphi-\psi)]}\right\}\right]. \end{aligned}\right\} \tag{7}$$

The complete field $H_x = H_{ox} + h_x$; $H_z = H_{oz} + h_z$:

$$\begin{aligned} H_x &= M\left\{\frac{3\sin\varphi\cos\varphi}{r^3} + \frac{\mu}{R_\odot r^2}\left[\cos\varphi\ln\frac{2r}{R_\odot[1-\cos(\varphi-\psi)]} - \left\{2\cos\varphi - \frac{\cos\varphi-\cos\psi}{1-\cos(\varphi-\psi)}\right\}\right]\right\}, \\ H_z &= M\left\{\frac{3\cos^2\varphi-1}{r^3} - \frac{\mu}{R_\odot r^2}\left[\sin\varphi\ln\frac{2r}{R_\odot[1-\cos(\varphi-\psi)]} - \left\{2\sin\varphi - \frac{\sin\varphi-\sin\psi}{[1-\cos(\varphi-\psi)]}\right\}\right]\right\}. \end{aligned} \tag{8}$$

It is easy to see from (8) that the ratio H_x/H_z is a function of a single parameter $\mu = (2\pi u\sigma_1 R_\odot/c^2)\sin^2\psi$. From this we can draw the first conclusion which is, by the way, quite evident. The sources of matter located at the pole do not distort the initial field. It is quite evident from photographs of the corona obtained during the eclipses of 1952 and 1954 (e.g., [8]) that the polar brushes are reminiscent of the lines of force of a dipole field. An examination of an ideally minimum corona is of particular interest. In this case, the sources of the matter should be located exactly on the equator ($\psi = 90^\circ$). The expression for the magnetic field intensity in the solar corona assumes the form

$$\begin{aligned} H_x &= M\left\{\frac{3\sin\varphi\cos\varphi}{r^3} + \frac{\mu\cos\varphi}{R_\odot r^2}\left[\ln\frac{2r}{R_\odot(1-\sin\varphi)} + \frac{\cos\varphi}{1-\sin\varphi}\right]\right\}, \\ H_z &= M\left\{\frac{3\cos^2\varphi-1}{r^3} - \frac{\mu}{R_\odot r^2}\left[\sin\varphi\ln\frac{2r}{R_\odot(1-\sin\varphi)} - 1\right]\right\}. \end{aligned} \tag{9}$$

Figure 2

Figure 3

Figures 2 and 3 show the location of the lines of force of a disturbed field for the case when the sources of matter are located on the equator ($\psi = 90^\circ$) and in the middle latitudes ($\psi = 45^\circ$), respectively. In figure 2 the circles indicate the behavior of the envelopes for fans and polar rays; the solid curves show the lines of force of the disturbed solar field. Our attention is attracted to the good agreement between the shape of the lines of force of the disturbed magnetic field of the sun and the ray structure of the minimum and intermediate corona.

Many authors have pointed out that the structure of the inner corona owes its existence to the presence of local magnetic fields; van de Hulst extended this assumption to include polar brushes. It would be quite logical to ascribe the "magnetic" occurrence to fan-like forms. In 1953, V. A. Krat [9] proposed that "the direction of the magnetic lines of force coincides with the direction of coronal rays." However, at that time, it was unfounded, and sounded quite unconvincing. It was completely unclear why the magnetic fields can assume such a strange configuration. It was just this fact which was the main barrier to an understanding of the nature of coronal forms. The present work eliminates this difficulty; the radial flux of a conducting liquid moving in a dipole field creates, in the surrounding space, an induced field which, combining with the initial field, gives a picture of the lines of force which coincides with the shape of coronal rays even in details. The difficulty in explaining the comparatively long lifetime of coronal rays is automatically eliminated. With a field intensity of H = $= 3 \times 10^{-3}$ gauss*) and a ray thickness $r = 0.1\,R_\odot$, the lifetime of the ray

*) Computed from (9) for a point $2R_\odot$ from the surface of the sun and $0.05R_\odot$ from the ray's axis, assuming that the magnetic field intensity at the pole of the sun ~ 0.1 gauss.

with respect to diffusion

$$\tau_{diff} = \frac{e^2 b}{kTc^2} H^2. \qquad (T = \mathrm{const}).$$

where b is mobility, e the electron charge and T kinetic temperature. When $T = 10^6$ ° and $N = 10^6$ particles/cm^3, the lifetime $\tau_{diff} \approx 10^7$ sec. The ray will be stable with respect to diffusion.

We can use still another fact to compare theory with observation: making the highly improbable assumption that the boundaries of the eastern ray in corona 1954.505 coincide with the lines of force (this ray lies in the picture plane), we can select μ such that the form of the lines of force will accurately agree with the outlines of the ray. But we know the apparent expression for μ (for corona 1954.505 $\mu \sim 1$):

$$\mu = \frac{2\pi u \sigma_1 R_\odot}{c^2} \sim 1.$$

At a distance $R = 2R_\odot$, $\sigma_1 \sim 90$. If $n \sim 10^6$ particles/cm^3, $T \sim 5 \times 10^5$ ° and $H \sim 0.035$ gauss, $u \sim 120$ km/sec. The velocity is less than that obtained from geophysical observations ($\sim 10^8$ cm/sec), but such agreement should also be considered good.

In conclusion we should note one more thing; the form of the lines of force of the magnetic field of the solar corona changes radically if the matter in the ray does not move away from the sun but if, like the stream of a fountain, it returns. In this case the magnetic field would be of the approximate form shown in figure 4. Possibly, however, a certain part of the matter in the lower regions of the ray returns to the sun, i.e., there exists, so to speak, a "counter-current." This can lead to the formation, within helmets, of unique arcs and envelopes [1]. In any event this fact should be considered and should be examined in more detail.

Figure 4

QUESTIONS AND ANSWERS

A. I. LEBEDINSKII. What forces compress the ray into a fine needle?

E. A. PONOMAREV. In the present work this question is not examined. However, forces can be found from the least-energy principle.

S. B. PIKEL'NER. Aren't there contradictions in the sequence of the solution of the problem? First it is assumed that heating occurs in the magnetic "sack" and then that the field forms during the movement of a stream.

PONOMAREV. In posing and solving the problem there were no assumptions made as to the heating of gas in the "magnetic sack." It is assumed that there is a directed movement of the conducting gas in the external field and that alone.

N. A. IAKOVKIN. Do the magnetic lines of force rotate with the sun or do they lag behind?

PONOMAREV. Of course, magnetic lines of force rotate together with the sun.

E. I. MOGILEVSKII. What initial velocity should be imparted to the stream to insure that the corpuscular stream emerges from the coronal region, taking the influence of the magnetic field into account?

PONOMAREV. The velocity of the stream is not given in the computations and has not been determined independently. The velocity enters only in the form of the product $u\sigma_1 F$ which is determined from observations. Computing the electrical conductivity from known formulas we can estimate approximately that $u \sim 10^7$-10^8 cm/sec.

IA. G. BIRFEL'D. How does a beam pass through plasma?

PONOMAREV. We assume a uniform current of conducting liquid, and examine its interaction with the magnetic field for the case of steady movement. We can say nothing either of the history of the current or of the causes of its formation. We consider that it already exists and we are interested in how this existence is expressed in the distribution of the magnetic field in the corona.

V. A. KRAT. What velocities were assumed in the computations?

PONOMAREV. Velocities were not examined, but the parameter μ was selected.

PIKEL'NER. Can it be said that there is no corona but only streams?

PONOMAREV. No. Hydrodynamic conditions do not exclude hydrostatic conditions.

A. B. SEVERNYI. How is the general magnetic field disrupted? After all, it is perpendicular to the stream.

PONOMAREV. The stream "draws" lines of force after it. Here the liquid performs work in "deforming" the magnetic field. Of course, there must have been sources of energy capable of covering this energy expenditure.

LITERATURE CITED

[1] Vsekhsviatskii, S. K., E. Ia. Bugoslavskaia, and A. N. Deich. Trudy ekspeditsii po nabliudeniiu polnogo solnechnogo zatmeniia 19. VI 1936. 1938. Chapter 1.

[2] Bugoslavskaia, E. Ia. Moscow; Universitet. Gosudarstvennyi Astronomicheskii Institut imeni P. K. Shternberga, Trudy, 19: 1950.

[3] van de Hulst, H. C. Article in The Sun, edited by Kuiper. Chicago, University of Chicago Press, 1953. Ch. 5, p. 207. Russian translation published by Izdatel'stvo Inostrannoi Literatury, 1957.

[4] Nikol'skii, G. M. Astronomicheskii Zhurnal, 31(4), 1954.

[5] Vsekhsviatskii, S, K., G. M. Nikol'skii, E. A. Ponomarev, and V. I. Cherednichenko. Astronomicheskii Zhurnal, 32(2), 1955.

[6] Babcock, H. W., and H. D. Babcock. Astrophysical Journal, 121, 1955.

[7] Kiepenheuer, K. O. Zeitschrift für Astrophysik, 10, 1935.

[8] Vsekhsviatskii, S. K., and G. M. Nikol'skii. Astronomicheskii Zhurnal, 32(4), 1955.

[9] Krat, V. A. Akademiia Nauk SSSR. Komissiia po Issledovaniiu Solntsa, Biulleten', No. 8-9, 1953.

DISCUSSIONS ON THE LECTURES OF E. R. MUSTEL', A. B. SEVERNYI, S. K. VSEKHSVIATSKII ET AL., G. M. NIKOL'SKII AND E. A. PONOMAREV

K. P. STANIUKOVICH. Since on the sun streams of gas exist which have velocities of hundreds of km/sec (up to 1000 km/sec), when these streams are braked in shock waves the temperature can increase to 1,000,000° (and more), which is quite sufficient for the excitation of thermonuclear reactions even in the outer parts of the sun. With temperatures of the indicated order of magnitude, the volume of matter does not play an essential role; thermonuclear reactions in the presence of hydrogen and deuterium on the sun can occur even with small amounts of matter. Therefore, I agree with the opinion of A. B. Severnyi as to the possibility of explaining flares as the explosion of "hydrogen bombs" on the sun. This hypothesis is interesting and requires a systematic analysis and development.

A. B. SEVERNYI. Unsöld considers that great energy is required for the formation of a stream; therefore, we must continue to seek nuclear reactions.

V. A. BRONSHTEN. We should not confuse the question of what observations yield in respect to the nature of coronal rays with the possibility of finding a theoretical mechanism which would explain the nature of these rays, in particular, the hypothesis of corpuscular streams. A number of coronal photographs during the eclipses of 19 June 1936 and 30 June 1954 show coronal rays up to 8-10 $R_{\odot}$ in length. Several of them are radial, others at an angle. The ray at the eastern limb of the disk on 19 June 1936 is of particular interest; it is noticeably bent, which shows the manifestation of the influence of local magnetic fields on the sun connected with spots. Far from the sun, the ray expands and weakens, blending with the background.

Thus, the structure of the rays of the far outer corona rather confirms the hypothesis of corpuscular streams. In this case I shy away completely from its theoretical interpretation.

E. R. MUSTEL'. First, I would like to make several comments on the concentration of corpuscles in streams. Several basic concepts of the given question have already been presented in the introductory lecture, where I pointed out that in my opinion the most probable estimates of the concentration are those based on study of magnetic storms and the emission spectra of polar aurorae. These estimates for the concentration of protons are as follows: $n_p \approx 1$ cm^{-3} for moderate disturbances and n_p between 25 and 100 cm^{-3}

for strong disturbances.

Nevertheless, in the preceeding discussions these estimates have been disputed without sufficient grounds, and it was asserted that those estimates based on study of the polarization of zodiacal light and the study of accelerations observed in comet tails would be more valid. I have already pointed out that these latter methods yield very indefinite results. However, the given question will be discussed in greater detail in subsequent lectures, and I would like only to point out the following facts.

Considering that polarization of zodiacal light is caused by electrons, Siedentopf, Baer and Elsasser have found that near the earth the corresponding concentration of electrons, and subsequently also protons, is close to 10^3 cm^{-3}. Here authors defending the coronal concepts of current assume that in this case as well we are dealing with streams of protons and electrons from the sun moving at a velocity of about 1000 km/sec and having the indicated concentration $n_p \approx 10^3$ cm^{-3}.

On the other hand, it is known that the isophotes of zodiacal light are stationary and are always of a completely smooth nature. This indicates that from the point of view of the given concepts, the earth is always in the field of relatively equally distributed (in space and time) streams with v = 1000 km/sec and $n_p \approx 1000$ cm^{-3}.

At the same time it is known that even in years of maximum solar activity the earth's magnetic field is quiescent between individual disturbances. In other words, in the examined case, we should have considered that corpuscular streams, with the above-indicated parameters, correspond to a quiescent magnetic field, but this cannot be, since the energy transmitted by such currents with v = 1000 km/sec and $n_p \approx 10^3$ cm^{-3} is so great that these streams cannot help but create noticeable disturbances in the earth's magnetic field.

Furthermore, let us assume for the time being that the indicated currents actually correspond to a quiescent field. But whatever theory of magnetic disturbances we use, the concentration of atoms corresponding to strong disturbances and a quiescent field should differ by 3-4 orders of magnitude. In other words, strong storms should correspond to concentrations of 10^6-10^7 cm^{-3}, which is already quite absurd, and differs by 10^4-10^5 times from that which we would get if the theory of geomagnetic disturbances were used. Moreover, streams with v = 1000 km/sec and concentrations of 10^6-10^7 cm^{-3} correspond to energies greater than the solar constant. Approximately the same argumentation is applicable to comets as well.

Let us return again to the "coronal" concepts of corpuscular streams. It should immediately be stressed that we must differentiate between the question of the movement of matter in coronal rays with velocities up to several km/sec and even in a number of cases to ten km/sec, and the hypothesis which states that in the outer parts of coronal rays, matter moves with "geophysical" velocities of the order of 1000 km/sec. We cannot doubt the first, since the very fact of the existence of extended coronal rays as solar formations attests to the movement of matter away from the sun, and we should recognize the service done by Ponomarev in processing the physical mechanism which determines the kinematics and dynamics of matter in the corona. The concept of coronal rays as well as streams of geoactive corpuscles is another matter. I completely disagree with these concepts. I have already enumerated my main objections; these are objections connected with the radiality of solar corpuscular streams. Let us make a number of additional comments.

A number of observational facts presented in one of my works (Astronomicheskii Zhurnal, 32: 177, 1955) attest to the fact that at the base of rays, right up to heights of 0.5 $R_{\odot}$ - 1 $R_{\odot}$ from the sun's surface, radial efflux velocities cannot exceed several km/sec. Accordingly, we should introduce some mechanism of the acceleration of coronal matter in the outer parts of the rays. This acceleration mechanism is as yet completely hypothetical. In the mechanism examined by Ponomarev, the main force which determines the acceleration outward is the pressure gradient connected with the temperature drop. We cannot tell anything from the magnetic forces themselves, since it is known that magnetic forces usually only decelerate matter.

But in such a case it should be noted that the efflux of matter should be most intense not above prominences, where the extended coronal rays*) are directly observed, but above faculae. It is known that actually, directly above faculae, there are regions of increased luminescence in coronal lines, whereupon these regions are extremely hot. Accordingly, it is actually here that we should expect a great temperature drop, although again it is difficult to identify broad coronal rays above faculae with geoactive streams, since above faculae as well, coronal rays are usually not radial. On the other hand, in the base of "helmets," which are the lower part of extended coronal rays, monochromatic coronal luminescence is not amplified. Moreover, in the

*) which are also considered as geoactive streams.

"helmets" above prominences, light "arcs" may be observed which are separated from each other by a dark space across which the pressure gradient naturally cannot act. Therefore, the hypothesis that the pressure gradient plays an especially great role in helmets and higher is not based on any physical premises.

Moreover, it is quite clear that Ponomarev's accelerating mechanism should be most effective in the lower layers of the corona where there is a noticeable drop in temperature. However, undoubtedly in the outer parts of the rays, greater isothermy is observed than in the lower parts. Also, as I have already pointed out in the work cited above there are practically no noticeable movements to the outside up to distances 0.5 $R_{\odot}$ - 1 $R_{\odot}$ from the sun's surface!

I would like to add the following to what has been said. It seems probable that there is much more matter in the corona in the outer parts of the rays above faculae, but it is included within a wide beam, while in rays above prominences, there is less matter, but it is mostly focussed and therefore appears in the form of bright rays. This supposition should be verified by direct photometry of both types of rays.

The next concept is as follows. Extended coronal rays narrow outward, judging from their form. Therefore, when a ray moves in space (caused by the sun's rotation), it will pass by the earth in much less time than is usually taken by disturbances (A. I. Lebedinskii has already mentioned this). However, this viewpoint can be taken even more seriously if we consider that in years of minimum, the disturbances last sometimes up to ten days, which follows from figure 13 of my introductory lecture (p. 22) [translated by A. M. S. (tr.)]. In this case, the discrepancy between the time that the earth is actually located in the stream and the time which we would expect from the hypothesis of coronal rays (as geoactive streams) should be no less than three orders of magnitude. True, the authors of this hypothesis assumed that coronal rays diverge once again at great distances from the sun. However, one hypothesis should not be used to construct a multitude of others which derive from nothing and would be highly improbable.

Finally, we should bear in mind that, in contradiction to what has already been proposed, at present there is no sufficiently convincing evidence of the geophysical nature (comparisons) which would speak in favor of the examined coronal hypothesis of corpuscular streams. The negligible amount of comparisons made up to the present time carry no weight, the more so since

basically these comparisons are of a completely frivolous nature. Thus, e.g., many people consider that the large eastern coronal ray observed during the eclipse of 25 February 1952 produced disturbances which then repeated themselves. At the same the direction of this ray comprised an angle of about 25° with the direction to earth! Such comparisons are not worth talking about, the more so since we know nothing of the direction of the rays with respect to the meridional plane on the sun; moreover, we do not even know whether these rays preceed their base or lag behind it. Furthermore, there are always so many coronal rays that when making such comparisons, there are a great many discrepancies.

Considering everything that has been said, I personally do not think it obvious which arguments and concepts speak in favor of the coronal hypothesis of corpuscular streams. On the other hand, all the data of a geophysical nature (radiality, etc.), and also other data, contradict this hypothesis.

In conclusion it should be noted that despite the remarks made, the study of motions and the dynamics in the outer corona and particularly in rays is an exceptionally important problem. In particular, the idea that the interaction between coronal rays is caused by the presence in them of stream systems where the speeds of protons and electrons are somewhat different, is a very interesting one. However, it is quite obvious that for effective interaction, high general velocities of the movement of matter in the rays are not required. Thus we know that "helmets" and their extensions (extended rays) usually lie in one general straight axis, i.e., the deviation from radiality here is approximately uniform. In addition, in the "helmets," i.e., in the lower parts of the corona, the general velocities of matter are very low (see the above reference), no more than several km/sec.

Finally, V. V. Vitkevich's results are very interesting. These have to do with the presence of electron heterogeneities in the corona with a concentration of the order of $n_e \approx 10^4$ cm^{-3}, located at distances 10-15 $R_{\odot}$ from the sun. This latter fact attests to the extreme complexity of the structure of the outer corona. Such investigations should be continued.

G. M. NIKOL'SKII. The assumption of low velocities in the base of the ray ($\sim 10^5$ cm/sec), on the basis of the assumption that the ray is a stream of matter, yields velocities in the outer parts of the rays $\sim 10^8$ cm/sec. This follows from the continuity equation

$$vN(r)\rho^2 = \text{const}$$

and from data (observational) on the distribution N(r) in the ray. The velocity v will increase $\sim r^n$, where n is the gradient of a decrease of N(r). Computations give $v \sim 10^8$ cm/sec in outer parts of the corona.

However, the established, as it were, absence of macroscopic velocities in the non-eclipse observations of the inner corona do not exclude the existence of considerable microscopic velocities in rays where the rays are visibly stationary. Here we should note that non-eclipse observations made in emission lines do not give us a picture of movements in rays, since we know that there is a lack of correspondence between regions of increased luminescence in coronal lines and "white" rays. At the same time, Waldmeier's recent observations indicate the existence of mass macroscopic movements in the inner corona, which follows from the lifetime of monochromatic rays, ~ 15 minutes, which he established.

S. B. PIKEL'NER. In examining a ray as a stream we should consider the place of formation of rapid particles. If they come from the chromosphere, the ray is a two-phase system; a great part of it is in equilibrium and the stream passes through it. If, however, rapid particles form in the corona, from the continuity equation we get motion of all matter of the ray upward, with gradual acceleration. Data on the asymmetry of lines attest, rather, to particles from the chromosphere. Ponomarev's theory is interesting and worthy of attention.

Not all streams of the corona can be geoactive. I believe that the estimate of the density of the stream is somewhat too high; it hardly exceeds 10^2 cm^{-3} for moderate disturbances. The slight divergence of the stream is also doubtful. In this case, there would be little probability of the current's striking the earth.

V. A. KRAT. The question of the mechanism of the ejection of geoactive particles has been of great interest at our meetings. The main thing now is to establish the location of the centers of geoactive corpuscular radiation on the sun's surface and to associate them with the actually observed phenomena. On the sun's surface, such regions can only be chromospheric layers and facular fields (which, as A. B. Severnyi has succeeding in establishing, are accumulations of small chromospheric flares). In this case we can estimate the velocity of ejections of corpuscles, and establish the fact that they exceed the critical velocity.

The question of the connection between flares and the phenomena in the outer corona should be examined separately since there are, as yet, no observational data for it.

E. IA. BUGOSLAVSKAIA. The coronal forms are determined by formations on the sun's surface; the question of their stability is connected with this. Coronal forms are disrupted, and the corresponding formations on the sun's surface disappear, but not immediately; it is interesting what the present theory gives in this case.

In the lectures we have spoken of the rays above prominences. Above faculae, there appear direct rays running in a broad but slightly divergent stream. The forms and interactions of coronal streams attest to the presence of electromagnetic forces.

The velocities of movement of matter along a ray can be determined only indirectly from photographs. In two cases, such velocities were estimated to be no less than 100 km/sec.

N. IA. BUGOSLAVSKAIA. 1. The prominence observed during the solar eclipse of 19 June 1936 attests to the transfer of matter of the prominence into the corona; like the prominence, it stopped glowing. In its place there remained coronal clouds of the same shape but considerably expanded. Part of the matter falls back and part evidently scatters.

2. The difficulties in explaining irregularities in the behavior of disturbances, as indicated by Mustel' from the point of view of the action of corpuscular streams, disappear, if we consider the possibility that the earth enters the corpuscular stream.

MORNING CONFERENCE
23 November

CONTINUATION OF THE DISCUSSIONS ON THE LECTURES BY E. R. MUSTEL', A. B. SEVERNYI, S. K. VSEKHSVIATSKII ET AL, G. M. NIKOL'SKII, AND E. A. PONOMAREV

S. K. VSEKHSVIATSKII. 1. Yesterday we heard convincing evidence that, according to Mustel', the mechanism of light pressure cannot explain the formation of streams. But even if such a mechanism were active, and rectilinear streams were to form (which actually cannot occur), would they pass through the corona? Here Mustel' and certain others defend the position that geoactive streams have nothing in common with the corona. But what does this mean? If they acknowledge that coronal matter is plasma, either the streams are formed by coronal electrons and protons, or they do not exist at all. There cannot be any other geoactive streams besides corpuscular streams. This would be the same as acknowledging the fact that streams do not exist. However, complete denial of streams means that all geophysical data have to be disregarded.

Thus, the concept that streams are not connected with coronal structure, which Mustel' suggested long ago, is logically unsubstantiated, and contradicts physical concepts.

2. Here Mustel' used alleged proof of the radiality and narrowness of geoactive streams, which therefore cannot be, as it were, coronal rays. However, it is actually the coronal rays that are characterized by narrowness and directedness. Furthermore, the conclusions of M. N. Gnevyshev and A. I. Ol' were obtained from statistics of the spottiness of the central regions of the disk as compared with the average geomagnetic features. Knowing about these deviating fields of spots, we should recognize that the relationships of Gnevyshev and Ol' are actually proof of the non-radiality of streams which is in complete agreement with the structure of the corona. The Gnevyshev-Ol' relationship attests only to the fact that the disturbed region, characterized in particular by spots, yields more coronal particles and consequently greater density in geoactive streams. The conclusions about the narrowness of streams are of the exact same statistical nature. They can in no way be an objection against the representation of coronal rays.

3. Everything that Mustel' has said about the alleged non-correspondence between coronal rays and geoactive streams is a misunderstanding. Our computations actually indicate the stability of coronal rays, their rotation with

the sun and accordingly, the obligatory nature of the 27-day recurrence. The pulsations of rays which Mustel' tried to attribute to our statements are simply untrue. Actually, we show that coronal radiation and structure are an important path toward understanding geomagnetic phenomena.

Mustel' is mistaken when he asserts that the recurrence of storms is observed only in pre-minimum epochs. Bartels' carpets prove that in the maximum epoch, sequences do exist, but they are less stable. This is understandable from the viewpoint of the concept of coronal streams, but completely unexplainable from the positions of Mustel's concepts.

E. I. MOGILEVSKII. 1. The interesting results of the photoelectric observations of emission in lines H_α, H and K in flocculi, given in the lecture by A. B. Severnyi, should be, as we know, diligently analyzed from the point of view of the computation of the experimental errors which arise during such highly accurate measurements. As has already been pointed out at the last plenum of the Solar Research Commission[*)], in the photoelectric installation of the Crimean Observatory the instrument polarization of light, occurring during reflection of light from the mirrors and the diffraction grating, is "analyzed" by the diagonal scanning mirror and by the concave photocathode of the photomultiplier. We can show that after the disgonal scanning mirror, whose reflection coefficient is T - T(λ), the light intensity is determined by the expression

$$I=I_0\frac{T\cos^2\gamma(P\cos^2\gamma+\sin^2\gamma)+\sin^2\gamma(\cos^2\gamma+\sin^2\gamma)-\sin^2 2\gamma.\ \sqrt{T}\ /2(1-P)}{\cos^2\gamma(\cos^2\gamma+P\sin^2\gamma)+T\sin^2\gamma(P\cos^2\gamma+\sin^2\gamma)+\sin^2 2\gamma.\ \sqrt{T}\ /2(1-P)}$$

where γ is the angle of incidence of light onto the diagonal mirror and p is the instrument light polarization. With a change from γ to $\gamma + d\gamma$ in the angle of incidence onto the scanning mirror, the computed magnitude dI with possible values of the parameters P and T (the latter are taken from measurements using the photoelectric apparatus of the Scientific-Research Institute of Terrestrial Magnetism[**)]) reaches several percents of I, which is comparable with magnitudes of the observed effect. Here we should remember that the concave photocathode of the multiplier of the Crimean Astrophysical Observatory apparatus is extremely sensitive to a change in the degree of polarization. Experiments made with the PEM-17 have shown that a change in the photocurrent is almost proportional to a change in polarization. There-

*) Komissiia po Issledovaniiu Solntsa

**) Nauchno-Issledovatel'skii Institut Zemnogo Magnetizma fore, in installations where the measurement accuracy should be high ($\lesssim$ 1%), it is necessary to take special care that the effect of instrument polarization be considered. The correlation shown in the article between the differences in the emission of wings in lines H_α and Ca II with a lack of connection between the magnitudes of the emission in these lines can be interpreted as a change in intensity of the output signal connected with the feeding of polarized light to the photocathode in the wings of the investigated lines.

2. The following remarks should be made about the question of the forces acting during the emission of the corpuscular geoeffective stream. The upper chromosphere and the corona are an almost ideal plasma. We can give strict proof that above active regions where a corpuscular stream is generated the determining forces will be local magnetic and induced electric fields. With any mechanism of the generation of the stream, the joint action of magnetic and electric fields determines the possibility of the emission of corpuscular streams. In addition, with the simultaneous action of H and E fields, the corpuscular stream is focussed in a radial direction from the sun. However, local magnetic-electric fields are "short-term" forces. Their effectiveness is comparable with other possible forces (e.g., with selective light pressure) at a distance $\sim$2.5-3 $R_\odot$, beyond the limits of which their influence rapidly decreases. In addition, it can be pointed out that if we consider the interaction of a corpuscular stream with an interstellar medium, the corpuscular stream cannot reach the earth if, during movement from the sun to the earth, the corpuscles do not receive additional impulses from the sun. The only force which can continually maintain the movement of the stream for a considerable distance from the sun is selective light pressure. Beyond the limits of the influence of magnetic-electric forces ($\doteq$ 3 $R_\odot$) the objections against the action of selective light pressure which were advanced in the lectures by I. S. Shklovskii et al. evidently lose their force. The proposed scheme was examined in detail in works carried out at the Scientific-Research Institute of Terrestrial Magnetism.

N. N. PARIISKII. The work by A. B. Severnyi is of very great interest. In particular, the new "mustache" phenomenon is interesting. Severnyi's arguments in favor of the deep origin of these "mustaches" does not seem convincing to me. In the given spectrograms it is not obvious that in most cases the absorption lines in the region of the appearance of "mustaches" were shifted toward the blue. The fact that "mustaches" arise in the "far wings of the lines" attests only to the movement of matter which forms this

phenomenon relative to the layers in which the central part of the line forms and can in no way serve as an argument in favor of the deep origin of this effect. But, on the other hand, the presence of such a shift attests to the fact that this formation occurs in layers higher than those which are responsible for the formation of the central parts of the absorption lines, i.e., the rather high parts. Attempts could have been made to explain the presence of "mustache" asymmetry both in the center and at the limb by the peculiarities of the direction of the magnetic field in these regions. In any event this phenomenon is of exceptional interest.

E. R. MUSTEL'. I would like to make further remarks on the coronal hypothesis of geoactive streams.

First of all, I do not agree that conclusions as to the laws of the distribution of velocities in the ray (along the ray) can be drawn from a study of the laws of distribution of density in a coronal ray. Such conclusions assume that the continuity equation obtains along the entire ray. However, we cannot agree with this. First, it is known that above prominences in the base of rays we usually observe closed "arcs", which already shows that a considerable part of the coronal matter in the base of the ray cannot proceed outward, and if it does move at all, it moves along closed trajectories. Second, a careful examination of coronal rays, particularly of drawings from photographs of the corona, show that the structure of each ray is very complex. In a number of photographs (or drawings) it is obvious that the main body of the ray consists of individual rays, while certain of them, judging from the photographs, reach only relatively low heights. In other words, from the observational viewpoint we should assume, rather, that the distribution of brightness along the ray is of a statistical nature, i.e., it is determined by the distribution of the individual components of the rays along the ray itself. In this regard, the assumption that one continuity equation holds along the entire ray is an arbitrary hypothesis, which contradicts observations.

As for the macroscopic velocities in the inner corona, they actually exist, but they are, according to Waldmeier, of a turbulent nature, and the velocity of this turbulence decreases with height.

The non-agreement in a number of cases between regions of increased luminescence in the coronal lines and the "white" regions (rays) is easily understood. The first regions correspond to an increase in temperature (or in general to conditions of anomalous ionization and excitation of atoms); the second, however, simply characterize the locations of greater density in the corona caused, as we would expect, by focussing (i.e., electromagnetic) factors. However, in all cases, the radiation in coronal lines is an inseparable property of all coronal ions (in whatever region they happen to be) and, accordingly, from a shift in the lines, we can always judge movements in the corona.

The question of the passage through the corona of streams of atoms, passing downward from the chromosphere, has already been treated by me in one of the answers regarding my introductory lecture. In particular, disturbances from chromospheric flares show directly that the assertion "there cannot be any geoactive streams except coronal streams" is wrong.

Further, naturally, coronal rays in their outer parts are narrow and oriented, since each coronal ray is directed somewhere. However, the narrowness of the rays has a somewhat specific connotation in the coronal hypothesis of corpuscular streams. The geophysical observations attest to the narrowness of the solid angle of the streams; here, however, we are simply speaking of the narrowness of rays which implies complete disagreement between the corona and its assumed influence on the earth. The introductory lecture discussed this in great detail and I am not about to repeat it. There we also mentioned the regularities in the recurrence of disturbances and changes in the direction of streams in the cycle and during the year.

V. A. KRAT. Severnyi has established the existence of ejections from chromospheric flares which occur with a velocity exceeding the velocity of the detachment; he also supported the hypothesis that facular fields are accumulations of small flares. Therefore, it can hardly be doubted that at least some part of the corpuscular streams of the sun are produced by facular fields. Mustel' is definitely correct in pointing out the existence of a connection between the development on the sun of active regions (mainly facular fields) and the phenomena in the earth's magnetic field.

In this regard it is still impossible to assert that no part of the coronal rays can reach the earth's orbit. However, the identification of all coronal rays with geoactive streams, as was done by Vsekhsviatskii and his associates, is completely unfounded, since the rates of movement of matter in coronal rays are unknown. It seems more natural to assume that most coronal matter, which converts into prominences upon cooling, falls back onto the sun's surface. Neither Vsekhsviatskii nor his associates have succeeded in determining the velocity of coronal streams of gas, but they point out that

these velocities can exceed the critical velocity. Therefore, we should state that the question of the efflux of matter from the corona still has to be investigated.

MAGNETIC DISTURBANCES IN THE REGION NEAR THE POLE AND THE EXISTENCE OF A SECOND ZONE OF THEIR INCREASED INTENSITY

by

A. P. Nikol'skii

The questions entering into the problem of solar corpuscular radiation can be divided into three main groups: the first deals with the mechanism of the radiation of corpuscles by the sun, the second with those physical processes which occur in solar corpuscular streams in interplanetary space, and in part along their path from the sun to the earth, and finally, the third group pertains to questions connected with the invasion of solar corpuscles into the upper layers of the earth's atmosphere and the appearance there of a number of physical phenomena.

Invasions of solar corpuscles into the earth's atmosphere cause magnetic ionospheric disturbances, polar aurorae and disturbances in earth currents. The study of these phenomena, in addition to their scientific interest (for solving the problem of solar corpuscular radiation), is also of great practical interest, since during periods of magnetic ionospheric disturbances, conditions of shortwave radio communication are sharply disrupted.

Despite great successes in studying the character of these phenomena, there still remains much that is not clear in the physical mechanism of their origin under the influence of solar corpuscles which invade the earth's atmosphere. Here it is not necessary to discuss in detail the existing theories of the phenomena, of which the best known are the Birkeland-Störmer, Chapman-Ferraro, Martin and Alfven theories. At present there is no generally accepted theory of these phenomena. It should be noted that in a number of theories general concepts play a large part. Thus, e.g., we may cite the work of Shuster who, criticizing the Birkeland-Störmer theory, maintained that the stream of solar corpuscles of one sign scatters before reaching the earth. Shuster's criticism would be justified if interplanetary space were a vacuum. However, at present there are grounds for assuming that in interplanetary space there is actually ionized gas of a definite density. If this is so, possibly Shuster's criticism would prove invalid for actual conditions. This example shows the need for continual control and re-examination of the already proposed theories of the geophysical phenomena on the basis of newly discovered facts and laws. If we do not do this, we are apt to deviate from reality and to convert such theories into purely formal structure.

The aim of the present lecture is to acquaint the participants of this meeting with certain new data and rules from the region of magnetic and, in

particular, ionospheric disturbances in high latitudes, revealed through the study of these phenomena at the Arctic Institute. These new facts pertain mainly to the distribution, during 24 hours, of irregular magnetic disturbances or, as they are called (incorrectly, in our opinion), the daily variation of magnetic activity. It should be noted that study of the daily distribution of magnetic disturbances at present has not attracted the attention which it deserves. Actually, there can be no doubt that magnetic and ionospheric disturbances are caused by the invasion of solar corpuscles into the upper layers of the earth's atmosphere. There is also no doubt that the presence of a magnetic field in the space surrounding the earth cannot help but influence the stream of corpuscles approaching the earth. Finally, the fact that the orientation of the magnetic field with respect to the corpuscles flying toward the earth, because the axis of rotation and magnetization do not coincide during the day, does not remain constant, gives additional grounds for assuming that conditions of the invasion of corpuscles into the earth's atmosphere also change during the day. From all this it is evident that by studying the daily distribution of irregular magnetic-ionospheric disturbances we should expect to discover important and essential facts.

It seems that new facts would be useful for further processing of the questions of the theory of magnetic disturbances and polar aurorae and for explaining the mechanism of the effect of solar corpuscles on the upper layers of the earth's atmosphere.

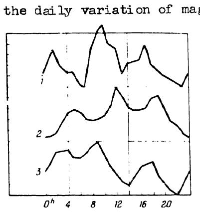
The data given here were obtained from the Soviet Aerial Expeditions (1948-1951) and drifting station "North Pole-2." These data pertain to the behavior of the magnetic disturbances in previously inaccessible regions of the central Arctic, in the regions of the earth near the Pole.

Observations of magnetic disturbances showed that the intensity and frequency of the appearance of irregular disruptions of the earth's magnetic field have a rather well expressed daily variation.

From observational data during the Second International Polar Year (1932-1933) Stagg [1] showed that at high-latitude stations there is one maximum in the daily variation of magnetic disturbances, a morning-daytime maximum at stations with $\Phi > 80^\circ$ (Φ is geomagnetic latitude) and an evening-nighttime maximum at stations with $\Phi < 70^\circ$. At stations located between geomagnetic latitudes 70° and 80° there are two maxima in the daily variation of magnetic disturbances, i.e., morning-daytime and evening-nighttime. Stagg concluded that the daily variation of magnetic disturbances in high latitudes is a function of local time.

Later, on the basis of more extensive data (19 stations with $\Phi > 60^\circ$ instead of the ten stations with $\Phi > 55^\circ$ examined by Stagg), we expressed the assumption [2] that morning-daytime magnetic disturbances are functions of Universal Time (UT) and the evening-nighttime disturbances are functions of local time. N. P. Ben'kova [3], who introduced observational data of magnetic stations in middle latitudes into the investigations, proposed that Stagg's conclusions are closer to reality, although she does not consider them to be indisputable. However, Stagg's conclusions were not developed further, and their physical explanation was not found.

At present it can be considered as established that the typical forms of the daily variation of magnetic activity in high latitudes are characterized by the presence of three maxima - morning, daytime, and evening. These are most clearly expressed at stations Godthaab, Bukhta Tikhaya and Wrangel Island (figure 1).



Universal time

Figure 1. Typical daily variation of magnetic activity in high latitudes. 1 - Godthaab, 2 - Wrangel Island, 3 - Bukhta Tikhaya

According to current data there is no simple relationship between the time of appearance of the morning and daytime maxima of magnetic activity and the coordinates of the stations; this can be seen from figure 2.

Analyzing the observational data from 20 magnetic stations located in the Arctic north of $\Phi = 60^\circ$ (including observations made by Soviet expeditions and drifting station "North Pole-2" in the central Arctic in the period 1948-1951) which, it is true, operated over a different time span (1882-1951) and for the most varied periods of observation (from 2 weeks to several years), the author considers [4] that the isolines of simultaneous (with respect to UT) appearances of maximum morning magnetic disturbances in high latitudes north of $\Phi = 60^\circ$ are a system of spirals (figure 3) emanating from the pole of uniform terrestrial magnetization. These spirals differ somewhat in form for various hours of UT, which can explain the non-agreement of the earth's rotational axis with the axis of magnetization.

At present, it can no longer be doubted that only solar corpuscles, penetrating the upper layers of the earth's atmosphere, can be the primary cause of irregular disturbances of the earth's magnetic field. The results

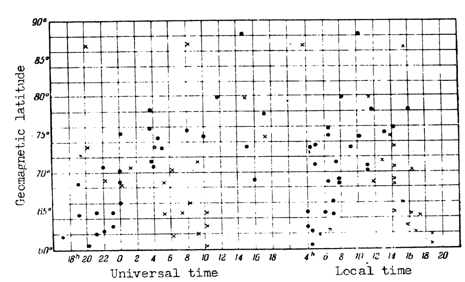


Figure 2. Time of the approach of morning (•) and daytime (x) maxima of magnetic activity vs the geomagnetic latitude, referred to Universal and local time.

of an analysis of the features of the occurrence of magnetic disturbances given by us in [5] gives grounds for assuming that the point of view of the phenomena of magnetic disturbances and polar aurorae developed in the theories of Birkeland [6] and Störmer [7] evidently corresponds quite well to reality. We should once again note, however, that this theory has been sharply criticized by Shuster [8], and up to the present time, the majority of geophysicists have regarded it as being poorly founded theoretically and unacceptable.

If, despite all this, the Birkeland-Störmer viewpoint is considered to be correct, the lines (figure 3) of the simultaneous occurrence of a morning maximum in the frequency and intensity of irregular magnetic disturbances given on the basis of observations of the disturbance field on the earth's surface, should be examined as the projection of those real lines perpendicular to which the trajectories of solar corpuscles descend when they themselves penetrate into the upper layers of the earth's atmosphere in the region near the Pole, a certain conditional sphere which is concentric with the earth's surface. Here the distribution of the approaching stream of solar corpuscles in spirals, i.e., the possibility of the invasion of corpuscles into the upper layers of the atmosphere, corresponding to a certain position of the spiral, is determined by the parameters of the corpuscles (mass and velocity).

Thus, in nature, the following evidently occurs. At some fixed moment of time, e.g., at 2000UT, the stream of solar corpuscles, depending on the spectrum of the mass and velocities of the particles, and also on their sign, enters the earth's atmosphere at places located along the spiral whose projection is also the spiral for 2000 in figure 3. The most intense morning magnetic disturbances develop in these regions of the Arctic. Further, as the earth rotates from west to east, if the solar corpuscles approach as before, the region of invasions of corpuscles and magnetic disturbances will, correspondingly, embrace high-latitude regions corresponding on the map to spirals of 2200, 2400, 0200, 0400, 0600, etc. and again up to 2000UT.

Figure 3. Diagram of the simultaneous appearance of the maximum of morning magnetic disturbances (the numbers of the isolines give the hours UT). a - the second zone of magnetic disturbances, b - the first zone.

It would be interesting to check the results obtained from observations in the Arctic for the Antarctic. In Antarctica, where the southern magnetic pole is located, the spirals should rotate counterclockwise; therefore the spirals in figure 3 were symmetrically transformed for this region (figure 4). For Antarctica we have data only from three stations - Cape Evans, Cape Denisson and Gauss Land. At these stations the morning maximum of magnetic disturbances occurs at 2200, 0300 and 0400 respectively. According to the isoline chart for these stations, the moment of the morning maximum is 2000, 0300 and 0800 respectively. The agreement between the observed data and the isolines is quite good. Only

for Gauss Land is there a 3-4 hour discrepancy.

Analysis of the observational results of magnetic disturbances in the Arctic, which we cannot dwell on here, also made it possible to draw the conclusion [4] that in the region near the Pole, in addition to the well known zone of maximum recurrence and intensity of polar aurorae and magnetic disturbances located at $\Phi = 65$-68°, there is a second zone of increased activity of these geophysical phenomena (figure 3) located near the Pole ($\Phi = 78$-80°).

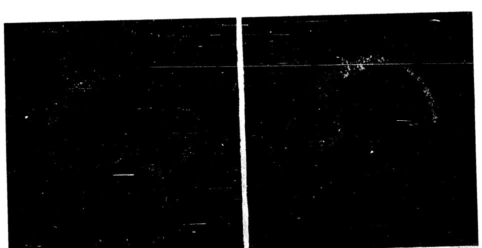
Figure 4. Hypothetical diagram of the simultaneous appearance of the maximum of morning magnetic disturbances for Antarctica.

This conclusion, based on experimental data, was recently confirmed theoretically. Alfven [9], examining the theoretical question of the physical mechanism of the occurrence of magnetic disturbances and polar aurorae, came to the conclusion that in addition to the ordinary zone of polar aurorae and magnetic disturbances, there should exist still another inner zone of increased intensity of these phenomena. This zone, according to Alfven, should be located at $\Phi = 80^\circ$.

A comparison of the experimental data obtained from magnetic disturbances in high latitudes with Birkeland's laboratory experiments and the results of Störmer's theoretical investigations can be useful in explaining the mechanism of the occurrence of these phenomena under the influence of solar corpuscles, and they show the direction which further theoretical examination of the given group of questions should follow.

From Birkeland's experiments it is known that under definite experimental conditions, cathode rays (electrons) settling on a magnetic sphere - "terrella" located in a vacuum, cause illumination on it, in the form of a spiral located around the magnetic pole and emanating from it.

From these experiments it follows that the settling of cathode rays onto the "terrella" occurs such (figure 5) that on its southern pole the illumination forms a spiral rotating counterclockwise. However, the southern pole of the "terrella" corresponds to that magnetic pole of the earth which is located in its northern hemisphere in the Arctic.



a b

Figure 5. The settling of cathode rays onto a "terrella" in Birkeland's experiments. a - on the southern pole of the "terrella" (corresponding to the Arctic), b - on the northern pole of the "terrella"

A comparison of the forms of the spirals in Birkeland's experiments with the spirals of figure 3 shows that they rotate in opposite directions. We know that the direction of rotation of the spirals is determined by the sign of the charge of the particles or by the poles of the magnetized sphere. In addition, we can draw the same physical interpretation both from Birkeland's experiments and from the experimental data in figure 3. On this basis, we can conclude that solar corpuscles penetrating toward the earth in the Arctic region near the Pole and causing morning magnetic disturbances are evidently positively charged. Most likely, these are protons. We can find confirmation of this in the results of spectrographic investigation of polar aurorae. Hydrogen lines were detected in aurorae spectra where their Doppler shifting indicated protons approaching the earth with a velocity of 800-3000 km/sec.

Regularities of the geographic distribution of morning magnetic disturbances which were found not only agree well with Birkeland's experiments, but in turn lend good support to the results of the theoretical examination of the movement of electrically charged particles in the field of the magnetic dipole, advanced by Störmer [7, 10].

Mathematical computations of the trajectories of charged corpuscles in the magnetic dipole field have shown [10] that the geometric location of the

points where the trajectories intersect the sphere surrounding the magnetic dipole is a spiral emanating from the pole of the dipole (figure 6). The position of the points on the spiral is determined by values of the parameter γ:

$$-1 < \gamma < r/2c \quad \text{where } c = \sqrt{\frac{Me}{mv}}$$

The direction of rotation of the spiral is determined by the pole of the magnetic dipole and the sign of the charged particles.

Störmer showed that the angular distance θ from the Pole of those places where solar corpuscles can penetrate is determined (for $\gamma = -1$) by the equation

$$\sin\theta = \sqrt{2r}\sqrt{\frac{mv}{Me}}.$$

where r is the distance from the center of the earth to the lower boundary of the polar aurorae, M is the magnetic moment of the earth, e is the charge of the corpuscle, m is the mass of the corpuscle, and v is its velocity.

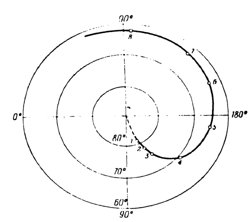
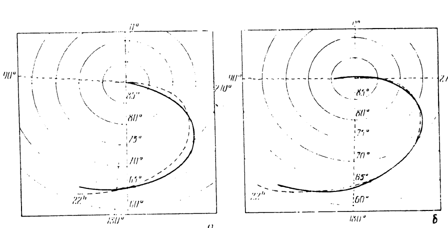


Figure 6. The geometric location of the points of intersection by the trajectories of charged particles of the sphere surrounding the magnetic dipole (according to Störmer). 1 - γ = -0.1; 2 - γ = -0.2; 3 - γ = -0.3; 4 - γ = -0.5; 5 - γ = -0.7; 6 - γ = -0.8; 7 - γ = -0.85; 8 - γ = -0.9.



a б

Figure 7. A comparison of the isoline of the simultaneous appearance of the morning maximum for 2200 and Störmer's theoretical curve. a - the case where the pole of Stormer's dipole coincides with the pole of uniform terrestrial magnetization; b - the case where the pole of Störmer's dipole is shifted somewhat relative to the pole of uniform terrestrial magnetization.

Figure 7 shows a single-scale representation of Störmer's theoretical curve and the isoline of the simultaneous appearance of the morning maximum of magnetic disturbances corresponding to 2200UT. The isolines corresponding to other hours of the day do not give as good agreement. The choice of any single isoline seems quite well founded because of the following. The curve obtained by Störmer pertains to a magnetic dipole having magnetic moment $M = 8.52 \times 10^{25}$ CGS. We can assume that at any moment of time during the day, the earth's magnetic field is so criented with respect to the line earth-sun that its effective influence on the approaching stream of solar corpuscles will most closely coincide with the influence of the pole of the dipole whose magnetic moment $M = 8.52 \times 10^{25}$ CGS.

When examining the extent of the agreement of these curves, we must consider that 1) the accuracy of drawing the isolines of the simultaneous appearance of maximum morning disturbances cannot be great, since actual data for such an enormous region of the earth's surface were insufficient and highly heterogeneous both with respect to observation time and their duration, 2) the magnetic moment of the earth differs from the moment used by Störmer, and 3) the computed position of the poles of uniform terrestrial magnetization possibly does not coincide with their actual position.

Figure 7 gives two examples of the comparison of curves when a) the pole of Störmer's dipole coincides with the pole of uniform terrestrial magnetization and b) the pole of Störmer's dipole is shifted somewhat with respect to the pole of uniform terrestrial magnetization in order that the curves will most closely agree. Such a shift is allowable on the basis of the reasons given above.

In any event, very good agreement is noted between the theoretical curve obtained by Störmer and the experimental curves obtained on the basis of magnetic observations in the Arctic.

In connection with this, we should mention the recent works of Bennett and Hulburt [11] who showed that use of the concepts of a self-focussing corpuscular stream can help overcome the main difficulty in the Birkeland-Störmer theory and can invalidate the criticism of this theory, which is based on the fact that a stream consisting of charged particles of one sign cannot exist due to electrostatic repulsion.

Various authors' computations of the self-focussing effect have shown that a stream of protons and electrons ejected from the sun at a wide angle are rapidly self-focussed in a narrow stream which actually consists of

protons alone. Such a stream will deflect toward polar zones in agreement with Störmer's computations. The authors have examined those astrophysical conditions under which the process of self-focussing can occur and have come to the conclusion that these conditions can actually exist.

On the basis only of magnetic data, the spirals of figure 3 can, despite the agreement with Birkeland's experiments and Störmer's computations, nevertheless raise some doubt, since the number of points used to compute them is comparatively small. Therefore, it proved very valuable to have found that the results obtained are well supported by observations of ionospheric disturbances.

We know that intense ionospheric disturbances in high latitudes are characterized by a number of phenomena and in particular by the fact that during vertical sounding there is a complete lack of reflections from ionospheric layers in all shortwave frequencies (anomalously high absorption - radio blackouts). This phenomenon is connected with the complete absorption of the energy of short radiowaves in the lower layers of the ionosphere, which is the result of a sharp increase in ionization at these levels. It should be noted that along the radio beam paths which pass through regions where anomalously high absorption is observed, shortwave radio communication is noticeably disrupted and in certain cases completely cut off.

The absorption of radiowaves in the ionosphere, observed throughout the entire illuminated hemisphere of the earth and connected with flares of UV radiation on the sun (the Dellinger effect), will not be examined here as being of another nature.

Anomalously high absorption (from now on we will call it simply absorption is observed in high-latitude regions. The maximum number of cases of absorption occurs approximately in the zone of maximum intensity and recurrence of magnetic disturbances and polar aurorae, located at geomagnetic latitudes $\Phi = 65\text{-}68^{\circ}$.

The occurrence of absorption of the examined type is connected, in a considerable number of the cases, with the simultaneous appearance of magnetic disturbances. This gave grounds for assuming that the penetration of solar corpuscles into the upper layers of the earth's atmosphere is the cause of such absorption. The regularities of the geographic distribution of absorption and changes in the probability of their appearance with time (daily variation, seasonal variation, etc.) have not been studied sufficiently until recently and there are still many questions which must be answered both for solving scientific problems and for the field of radio communications.

One of the little-studied questions in the relationship between geographic position and the time that the maximum occurs is the daily variation of the probability of the appearance of absorption.

From observations it is known that absorptions of the examined type most often occur during the first half of the day. However, it has not been possible up to now to discuss this in more detail because of the lack of systematized data from a broad network of ionospheric stations.

Meek [12] investigated absorption according to the data of 17 ionospheric stations. However, his conclusions, based on analysis of only 9 large ionospheric disturbances, require further confirmation. In 1954, Agy [13] and Cox and Davies [14] published results of investigation of absorption from observations of 19 ionospheric stations which, for the most part, operated from 1949 through 1953. Corresponding data for these and certain other stations are given in the table.

No.	Name of station	φ	λ	Time of maximum taken from the curves	Time of maximum (mean Greenwich)	Time taken from spirals of figure 3 (mean Greenwich)	Difference
1	2	3	4	5	6	7	8
1	Kiruna	67.8	20.5 E	6.0	5.0	2.0	+3.0
2	Tromsö	69.7	19.0 "	7.0	6.0	3.0	+3.0
3	Oslo	60.0	11.0 "	Very few cases			
4	Reykjavik	64.1	21.8 W	3.0	4.5	6.0	-1.5
5	Narsarssuaq	61.2	45.4 "	6.0	9.0	9.0	0.0
6	St. Johns	47.6	52.7 "	4.0	7.5	7.0	+0.5
7	Fort Chimo	58.1	68.3 "	6.0	10.5	11.0	-0.5
8	Clyde River	70.5	68.6 "	10.0	14.5	14.5	0.0
9	Ottawa	45.4	75.7 "	4.0	9.0	9.0	0.0
10	Churchill	58.8	94.2 "	9.0	15.0	14.5	+0.5
11	Resolute Bay	74.7	94.9 "	13.5	19.5	19.0	+0.5
12	Baker Lake	64.3	96.0 "	10.5	17.0	15.5	+1.5
13	Winnipeg	49.9	97.4 "	6.5	13.0	14.0	-1.0
14	Portage	49.9	98.3 "	No data			
15	Prince Rupert	54.3	130.3 "	6.5	15.0	15.5	+0.5
16	College	64.9	147.8 "	8.0	18.0	17.0	+1.0
17	Anchorage	61.2	149.9 "	6.0	16.0	16.5	-0.5
18	Point Barrow	71.3	156.8 "	10.5	21.0	18.0	+3.0
19	Adak	51.9	176.6 "	Very few cases			
20	Washington	39.0	77.5 "	4.0	9.0	9.0	0.0
21	Spitzbergen	78.0	15.0 E	7.0	6.0	6.0	0.0
22	Pukhta Tikhaya	80.3	52.8 "	7.5	4.5	4.0	+0.5

These articles [13, 14] contain information on the daily variation of a number of cases of absorption and of the time of their most frequent appearance.

The authors used the moment which corresponded to the maximum phase of the first harmonic of the Fourier series as the time of the maximum recurrence of absorption. In our opinion, considering the irregular nature of this phenomenon, it would be more correct to choose the time corresponding to the direct maximum from the curve of the daily distribution of the probability of absorption which, in fact, we have done. These moments for local time are taken from the curves of article [14] with an accuracy up to ±0.5 hours and are given in the fifth column of the table; these same moments for UT are given in the sixth column. The difference between the moments given in the sixth column and those corresponding to the maximum of the first harmonic of the Fourier series reaches four hours for certain stations.

Above it was shown (figure 3) that the isolines of the simultaneous appearance (UT) of the maximum of morning magnetic disturbances is a system of spirals emanating from the pole of uniform terrestrial magnetization.

Since it was shown that for all ionospheric stations for which we have information on magnetic activity the maximum probability of absorption in their daily variation agrees with the maximum of morning magnetic disturbances, for all stations listed in the table, the moments of maximum were taken from the spirals in figure 3, UT, with an accuracy up to ±0.5 hours. These moments are given in the seventh column of the table. It should be noted that on the basis of the magnetic data at our disposal, the spirals in figure 3 were drawn in the western hemisphere only up to $\varphi = 60^\circ$. Therefore, in order to give the moments of the maximum for stations such as Winnipeg, Ottawa and others, the spirals of figure 3 were extrapolated to $\varphi = 40^\circ$. The time of the maximum probability of absorption, obtained from the experimental curves (sixth column) practically coincides with the time taken from the spirals (seventh column). An examination of the differences (eighth column) shows that for 16 stations it is approximately ±0.5 hours, i.e., equal to the accuracy with which the moments were taken from the curves. Only for stations located in the zone of maximum magnetic disturbances (Kiruna, Tromsö and Point Barrow) did this difference reach greater values, 2-3 hours. Here it should be considered that the accuracy of drawing the spirals in figure 3 is actually least in this region, since the intensity of the morning maximum of magnetic disturbances at these latitudes is very low and the time of its appearance is very difficult to determine.

The following should be noted apropos of the results of this examination. The absolute maximum in the frequency of appearance of absorptions occurs primarily in the zone of maximum magnetic disturbances and polar aurorae, in which the nighttime magnetic disturbances reach their greatest development, while the time of the most frequent appearance of absorption for stations located in this zone (Churchill) agrees best with the morning magnetic disturbances. For stations located in the zone of polar aurorae, the maximum number of absorptions does not coincide with the nighttime maximum of magnetic disturbances, but appears 3-6 hours later. All these questions require further investigation and consideration.

From the above analysis of the daily variation of magnetic activity in high latitudes, the assumption was advanced that in regions near the Pole, north of $\Phi = 75^{\circ}$, there should be a second zone of increased intensity and recurrence of magnetic disturbances; the form and location of the proposed second zone are shown in figure 3. The observational results of absorption given in [13] and [14] support this assumption quite well. Thus, e.g., figure 8 shows that the greatest number of absorptions is observed at Churchill station which is located in the region of the well known first, more southerly zone of maximum intensity and recurrence of magnetic disturbances and polar aurorae. Then, further to the north, there is a sharp decrease in the number of cases of absorption up to the Baker Lake station, after which we again note a great increase up to Resolute Bay station. A comparison of these data with figure 3 shows that Resolute Bay station is actually located in the region of the second zone which we propose, while Baker Lake station is located between the first and second zone.

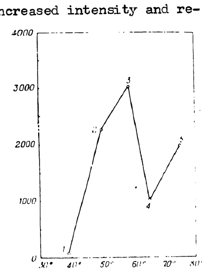


Figure 8. Frequency of the appearance of anomalous absorption vs. geographic latitude (according to Cox and Davies). 1 - Winnipeg, 2 - Washington, 3 - Churchill, 4 - Baker Lake, 5 - Resolute Bay.

Thus, the distribution of the appearance of absorption at 4 high-latitude stations located along the same meridian does not contradict the assumption of the existence, in the Arctic region near the Pole, of a second zone of increased intensity and recurrence of magnetic disturbances, but, rather, confirms it.

The assumption as to the possibility of the existence of a second zone is

also confirmed by data given in the above-cited work [13]. These data (figures 9 and 10) are given in the form of isolines of uniform recurrence of absorption and equal daily amplitudes of its variability. The crosses on these figures correspond to stations listed in the table (1-19).

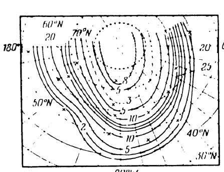


Figure 9. A map of the distribution of uniform frequency of the appearance of anomalous absorption for summer (according to Agy)

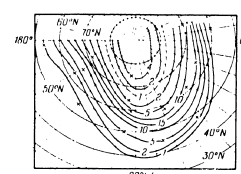


Figure 10. A map of the distribution of equal daily amplitudes of the daily variation of the frequency of the appearance of anomalous absorption (according to Agy)

An examination of these figures shows quite clearly that in the sector 90-100°W the total number of cases of absorption, as well as the daily amplitude of the recurrence of their appearance to the north of the first, more southerly zone ($\Phi = 50$-55°), decreases. However, this decrease continues only up to latitude $\Phi = 65^{\circ}$, after which the values of both characteristics of the phenomenon of absorption again noticeably increases. It has not been possible to state what occurs further to the north even closer to the Pole, because of the lack of active ionospheric stations at that location. It should be noted that such a latitudinal dependence in the changes of the total number of cases of the appearance of absorption and amplitude of their daily variation is best seen in summer. If we consider that the magnetic disturbances in the Arctic region near the Pole reach their maximum intensity also in summer, the connection between the phenomena of morning magnetic disturbances and morning absorptions becomes even more likely.

An examination of figures 8 and 9 shows that data on the geographic distribution of absorption and on daily changes in the probability of their appearance give good support to the assumption that there exists, in the Arctic region near the Pole, a second zone of increased intensity and recurrence of magnetic disturbances and that the position and shape of this zone in first approximation has been correctly depicted. Now there are grounds for assuming that this is also a second zone for ionospheric disturbances - more accurately, for anomalously high absorption.

The obtained results allow us to conclude that the geographical distribution of morning magnetic disturbances and the anomalously high absorption of radiowaves in the ionosphere, characteristic of high latitudes, are identical in a number of respects. This gives grounds for assuming that solar corpuscles which cause the appearance of morning magnetic disturbances are probably also the cause of a considerable number of cases of anomalously high absorption of radiowaves in the ionosphere.

Interesting data have been given in the article by Booker et al. [15]. The authors analyzed the reception of radio signals from a specific radio station in Ithica, south of Lake Ontario, and cases of the anomalous arrival of waves from unusual directions were identified with the reflection of radio waves from sporadic formations in the ionosphere which were connected with polar aurorae. The daily variation of such cases has two maxima, one of which occurs in the evening hours, and the other at 0300 (figure 11). This latter maximum, given in UT, coincides exactly with the corresponding spiral in figure 3.

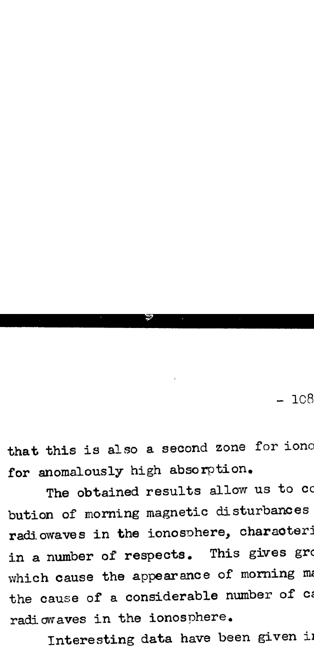


Figure 11. a - location of the receiving station, transmitting station and the directions from which the radio signals arrived, reflected from sporadic formations; b - daily variation of the frequency of cases of the arrival of radio signals reflected from sporadic formations.

The examined phenomena of various branches of geophysics give reasons for assuming that the regularities which we found correspond to the objective regularities of nature.

From all that has been said we can conclude that the results of our investigations, as well as the results of new investigations of a number of foreign geophysicists, give sufficient grounds for asserting that the basic positions of the theory of magnetic disturbances and polar aurorae expressed by Birkeland and Störmer are correct, to a considerable extent.

Since an explanation of the mechanism of the effect of solar corpuscles on the upper layers of the earth's atmosphere is one of the important questions involved in the problem of solar corpuscular radiation, further development of the Birkeland-Störmer theory on the basis of new experimental data is necessary.

LITERATURE CITED

[1] Stagg, J. Royal Society of London, Proceedings, Ser. A, 149: 298-311, 1935.

[2] Nikol'skii, A. P. Problemy Arktiki, No. 4: 5-43, 1938.

[3] Ben'kova, N. P. Nauchno-issledovatel'skii Institut Zemnogo Magnetizma, Trudy, 3(13): 15-40, 1948.

[4] "O novykh sovetskikh issledovaniiakh i otkrytiiakh v Tsentral'noi Arktike" (New Soviet investigations and discoveries in the Central Arctic), Akademiia Nauk SSSR, Izvestiia, Seriia Geograficheskaia, No. 5: 3-16, 1954.

[5] Nikolsky, A. P. Terrestrial Magnetism and Atmospheric Electricity, 52: 147-173, 1947.

[6] Birkeland, K. Norwegian aurora polaris expedition 1902-1903, 1: 11, 1913.

[7] Störmer, C. Problema poliarnykh siianii (The problem of polar aurorae), 1933.

[8] Shuster, A. Royal Society of London, Proceedings, 85: 44-50, 1911.

[9] Alfven, H. Tellus, 7(1), 1955.

[10] "Physics of the Earth," Terrestrial Magnetism and Atmospheric Electricity, 8: 599, 1939.

[11] Bennett, W. H., and E. O. Hulburt. "Theory of the aurora based on magnetic self-focusing of solar ion streams," Physical Review, 95(2): 315-319, 1954.

"Magnetic self-focussed solar ion streams as the cause of aurorae," Journal of Atmospheric and Terrestrial Physics, 5(4): 211-218, 1954.

[12] Meek, J. H. "Ionospheric disturbances in Canada," Journal of Geophysical Research, 57(2): 177-190, 1952.

[13] Agy, V. "Geographic and temporal distribution of Polar blackouts," Journal of Geophysical Research, 59(4): 499-512, 1954.

[14] Cox, J., and K. Davies. Canadian Journal of Physics, 32(12), 1954.

[15] Booker, H. G., C. W. Gartlein, and B. Nichols. "Interpretations of radio reflections from the aurora," Journal of Geophysical Research, 60(1): 1-22, 1955.

QUESTIONS AND ANSWERS

E. I. MOGILEVSKII. Are there differences in the geographic distribution of morning and evening disturbances? Why is the spiral distribution of the periods of disturbances given for morning disturbances?

A. P. NIKOL'SKII. We investigated both morning and evening magnetic disturbances. The rules mentioned most specifically in the lecture were for morning magnetic disturbances. On the basis of the results of investigation of magnetic disturbances in high latitudes, obtained in a number of our works, it seems to us that there should be no major difference in the nature and mechanism of the occurrence of morning and evening magnetic disturbances. Therefore, it is also possible that the regularities of geographic distribution of the phase of maximum evening magnetic disturbances will be similar to those of which we have been speaking.

A more definite answer to this question can be found in the lecture by O. A. Burdo [page 159 of original] who pointed out that in the daily variation of the component of the vector of a magnetic disturbance in the horizontal plane there are three maxima, coinciding exactly with the three maxima in the daily variation of magnetic activity (with respect to r_H^Y). One of these maxima is the morning maximum of magnetic activity which we investigated.

Burdo pointed out that the isoline of the simultaneous appearance of the phase of the nighttime maximum in the daily variation of the component of the vector of a disturbance in the horizontal plane is also a spiral, but rotating counterclockwise. This result lends good support to the fact that between the morning and evening magnetic disturbances there is evidently no essential difference in the sense of the nature and the mechanism of their appearance.

V. A. BARANUL'KO. How do the spirals behave for the morning disturbances of another, not maximum, intensity?

NIKOL'SKII. The time when the morning magnetic disturbances appear occupies part of a day, 5-6 hours. Morning disturbances with maximum intensity are observed, on an average, for 1-2 hours. Therefore, we believe that if we take the entire interval of the day when morning disturbances are observed at all the investigated stations, we should draw, on the corresponding map, not the lines pertaining to an hour, but bands pertaining to an interval of several hours.

On the basis of Burdo's lecture we can consider that this will hold for

the nighttime hours as well.

If, in his question, Baranul'ko wished to clarify how nighttime magnetic disturbances will behave in the sense of their geographic distribution, this is explained in the answer to the preceeding question.

B. M. IANOVSKII. How do you explain the appearance of the field of a magnetic disturbance?

NIKOL'SKII. In our investigation we devoted most of our attention to a study of the morphology of irregular magnetic disturbances, since it is they which actually determine the main content of magnetic storms. We made no attempt to explain the appearance of the field of magnetic disturbances - the deviation of the magnetic field vector from its value on quiet days.

As a result of the research conducted, we consider that the theoretical positions of Birkeland and Störmer most closely correspond to the results obtained. On the other hand, as we know, the field of a magnetic disturbance is still difficult to explain physically if we use the Birkeland-Störmer theory. In this regard, other geophysicists, using other concepts, developed theories of magnetic disturbances. Such theories are those of Chapman-Ferraro, Alfven, etc. In his lecture, Burdo first clearly showed that there is a very close connection between the undisturbed value and the intensity of irregular disturbances and deviation of the field vector. Therefore, it seemed that attempts to use the postulates of the Birkeland-Störmer theory to explain the magnetic field of disturbances should be continued, however, and should not be disregarded by geophysicists.

BARANUL'KO. Why is the method of harmonic analysis, used by Agy, unacceptable for determining the time of the phase of the maximum daily variation of anomalous absorption?

NIKOL'SKII. When studying irregular magnetic disturbances, we definitely concluded that use of harmonic analysis to study curves of the distribution of random occurrences in a particular time interval is unacceptable.

The daily variation both of magnetic activity and of anomalous absorption (studied by Agy) is none other than the curves of the distribution of the recurrence of random irregular disturbances. Therefore, the use of harmonic analysis in studying them does not agree with their physical nature but is of a formal character.

In this regard, when using the observational results given in Agy's article, we used the moment which corresponds to the direct maximum on the curve of the daily variation as the time of maximum recurrence of cases of anomalous absorption.

THE CONNECTION BETWEEN SOLAR ACTIVITY AND GEOMAGNETIC DISTURBANCES

by

A. I. Ol'

The aim of the present communication is to draw the attention of the participants of this meeting to some results of recent works on the problem of the connection between geomagnetic disturbances and solar activity.

Many statistical investigations have been devoted in the past to comparisons of sunspots and disturbances of the earth's magnetic field. The basic conclusion from them is as follows. Magnetic disturbances (mainly, the strongest ones) can be considered as being connected only with the largest spots, which occur relatively rarely. Most geomagnetic disturbances (in particular, those of moderate strength) and groups of sunspots are not connected. Newton [11] found that a noticeable increase in geomagnetic activity occurs after the passage through the central meridian of the sun only of spots of large area ($S > 1000$ millionths of a hemisphere [mh]). There were 70 such spots in 30 years (1914-1944). A considerable increase in geomagnetic activity, making it possible to speak of the existence of a definite connection between magnetic disturbances and spots occurs only for very large spots ($S > 1500$ mh), but in the 30 years, there were only 24 such spots. The relationship is somewhat more conspicuous if we select groups of spots near which bright chromospheric flares occurred (intensity 3 and 3+). In this case, the connection remains approximately as close, but the number of groups increases to 92 (the mean area of a group of spots is 642 mh). But in this case as well, the geomagnetic disturbances connected with spots form a small part of all disturbances (e.g., 612 storms were noted in 1914-1940 in the Pavlov Catalogue of Magnetic Storms).

If, however, to characterize groups of spots, we introduce the radio emission connected with them, the close connection with geomagnetic disturbances sharply increases. Denisse [8] discovered that the spots with which increased radio emission in the wavelength 1.77 m is connected are very closely associated with geomagnetic activity. On the other hand, spots devoid of radio emission cause a decrease in geomagnetic activity. Becker [1] found that pairs of spots (or groups of spots) located in the same heliographic longitude but in different solar hemispheres also lead to a decrease in geomagnetic activity.

Let us examine the results of a joint investigation by both authors (Becker and Denisse [2]). In 1948-1950, only 221 groups of spots in all were noted. These groups were divided into 114 type R groups (accompanied by radio emission) and 107 type Q groups (not accompanied by radio emission). R groups were sub-divided into 82 R' groups (single) and 32 RP groups (forming pairs

which are symmetrical with respect to the sun's equator). The Q groups were divided into 68 Q' groups and 39 QP groups on this same basis. Then, using the method of superimposing epochs, curves of geomagnetic activity were constructed (according to the international characteristic numbers C), while days where groups of R', RP, Q' and QP spots passed through the central meridian of the sun were considered separately as zero days. The results are shown in figure 1.

Figure 1

The height of the peak of magnetic activity for R' spots exceeds the height of the peak obtained by Newton for 24 very large spots selected over 30 years. Here, however, 82 groups were chosen from only three years. From this we can see the high effectiveness of the new method of selecting geomagnetically active groups of spots. Naturally, the results given above do not indicate that all R' groups caused magnetic disturbances. Fifty-five percent of these groups were accompanied by values of $C \geq 1.0$ (1-3 days after the central meridian had been crossed), i.e., by magnetic disturbances, but 19% of the groups were accompanied by values of $C \leq 0.5$, i.e., the geomagnetic field was relatively quiet. Becker and Denisse note that increases in magnetic activity connected with R' groups consisted either of storms with sudden beginning or of disturbances not displaying a tendency toward 27-day recurrence.

Simon [15] continued these investigations, studying the influence of chromospheric flares on the closeness of the connection between R spots and geomagnetic activity. Here he selected, for 1947-1954, 83 particularly eruptive spots, near which was observed at least double the number of flares observed, on an average, for all spots, for this time period, and 123 least eruptive spots, near which was observed, at most, half the number of flares, on the average, for all spots. These spots can be divided into R and Q spots:

	Number of R spots	Number of Q spots
Eruptive spots	29	54
Non-eruptive spots	40	83

As a result of investigations using the method of superimposing epochs, it turned out that an increase in geomagnetic activity is connected only with R spots, independently of their "eruptivity." This is understandable, since the characterization of the "eruptivity" of spots, as selected by Simon, is connected basically with the presence of weak flares, which comprise the overwhelming majority of all flares.

Then Simon selected (for the same years) 86 chromospheric flares of 3 and 3+ intensity. Of these, 55 were connected with R spots and 31 with Q spots. Flares connected with R spots were subdivided, depending on their position on the disk, into central (32 flares) and non-central, i.e., located at a distance more than 45° from the central meridian (23 flares). Such a subdivision was made for flares connected with Q spots (21 central eruptions). Use of the method of superimposing epochs showed that an increase in geomagnetic activity occurs only for flares connected with R spots, independently of their position on the disk. Central eruptions connected with Q spots even caused a slight decrease in geomagnetic activity.

Thus, we can assume that the radio emission of sunspots is accompanied by ejections of geoactive corpuscular streams from the sun. This agrees with the familiar hypothesis of I. S. Shklovskii, according to which ejections of corpuscular streams can cause oscillation of the plasma in the solar atmosphere, generating splashes of radio emission.

In addition, the investigations presented above show that a certain category of sunspots, namely, spots devoid of radio emission, cause a decrease in geomagnetic activity. In recent years, investigators have repeatedly come to the conclusion that the passage of certain solar formations through the central meridian is accompanied by a decrease in geomagnetic activity. Waldmeier [7] found that the occurrence of spots in a long-lasting M-region, i.e., in a portion of the sun's surface void of any visible manifestations of solar activity but causing disturbances of the geomagnetic field during a number of revolutions of the sun, leads to a destruction of the M-region, whereupon geomagnetic activity decreases; Bell and Glazer [3] supported the observations of Shapley and Roberts who showed that regions of increased emission of the green coronal line lead, in general, to a decrease in magnetic activity. From the data of observations at Sacramento Peak Observatory from 1950-1953, Bell and Glazer found that 8-11 days after the appearance of a region of strong emission of the green lines at the eastern limb of the sun, geomagnetic activity decreases. On the other hand, the regions of unusually weak green-line emission are accompanied by increased activity, in which case the disturbances of the magnetic field pertain to the category of storms which form part of the established 27-day sequence, i.e., storms characteristic of M-regions.

Bruzek [4] and Smyth [17] noted an analogous connection between storms of the indicated type and regions of weak luminosity of coronal lines. Bell and Glazer also investigated the important question of the validity of the so-called "axial hypothesis" which explains the annual variation of magnetic disturbances with equinoctial maxima by a change in the angle between the axis of the sun's rotation and the ecliptic, i.e., by a change in the heliographic latitude of the projection of the earth onto the solar disk. According to this hypothesis, in spring, magnetic disturbances should be caused mainly by those active regions which are located in the southern solar hemisphere, and in fall, by regions in the northern solar hemisphere. Regions of increased and weakened emission of the green coronal line were divided into two groups, "favorable," from the point of view of the axial hypothesis, and "unfavorable" regions. The first group contains regions located in the same solar hemisphere as the earth's projection, the second contains regions located on the other side of the solar equator, with respect to the earth's projection. Increases and decreases in geomagnetic activity were very rarely expressed, on an average, for "favorable" regions of weak and correspondingly strong coronal emission, and were absent during the passage of "unfavorable" regions across the solar disk.

Thus, the axial hypothesis has been supported. Analogous results were also obtained in the work by Bhargava and Naqvi [5] who studied a change in disturbance from one revolution of the sun to another for two very long 27-day sequences of magnetic disturbances observed in 1950-1953. In one sequence, the maximum disturbance was in autumn and the minimum in spring; in the other, vice versa - the maximum occurred in spring, the minimum in autumn. This is easily explained from the point of view of the axial hypothesis by the fact that the active M-region responsible for the first sequence was located in the northern hemisphere, while that causing the second sequence was in the southern solar hemisphere. Both M-regions should have a heliographic latitude somewhat exceeding 7°. Naqvi and Tandon [10] conducted a detailed investigation for the period 1930-1934. Three stable sequences were identified, one of which had a maximum in September (heliographic latitude of the M-region $\varphi > 7^{\circ}N$), another in March ($\varphi > 7^{\circ}S$), while the third had two maxima during the year which corresponds to an M-region located less than 7° from the equator.

All these facts attest to the validity of the axial hypothesis and indicate a small solid angle of corpuscular streams which cause magnetic disturbances occurring in stable 27-day sequences.

The problem of solar M-regions, i.e., active regions responsible for stable longlived sequences of geomagnetic disturbances clearly distinguishable in the 27-day calendars on the descending branch of the 11-year cycle, is at present close to being solved. The key to the solution of this problem was evidently the possibility of measuring weak magnetic fields on the sun's surface. At the end of 1952 in Pasadena (California), an instrument was set up which made it possible to measure very weak magnetic fields on the sun (Babcock [6]). The noise level of the instrument was about 0.1 gauss, which made it possible to measure fields with an intensity of about 0.3 gauss. The spectrograph slit passes across the solar disk 22 times in 80 minutes (diameter of the image, 40 cm), which makes it possible to get the general distribution of the magnetic field on the disk.

Observational results (Simpson, Babcock and Babcock [16]) have shown that on the sun there exist two types of regions with magnetic fields: bipolar and unipolar. Bipolar regions are associated with spots, bright calcium flocculi, and coronal arcs. The field intensity in them varies within wide limits, beginning with 1-2 gauss. In unipolar regions, the field intensity is 0.5-1 gauss; these regions are not connected with any formations in the photosphere or the solar corona. They are noted for their high stability (e.g., one of these regions passed across the central solar meridian 7 times, on 6 April, 3 and 30 May, 27 June, 23 July, 20 August and 15 September 1953). Considering these dates as zero days, the authors, using the method of superimposing epochs, constructed curves of geomagnetic activity (index K_p) and intensity of the neutron component of cosmic radiation (from observations at Climax, Colorado). The results are shown in figure 2. This figure shows the curves, constructed by K. K. Fedchenko, of the mean daily amplitude of the horizontal component of the geomagnetic field (R_H) from data of the Polar Observatory at Bukhta Tikhaya*). The maxima on the curves, despite the limitations of the data, are so sharply expressed that no doubt

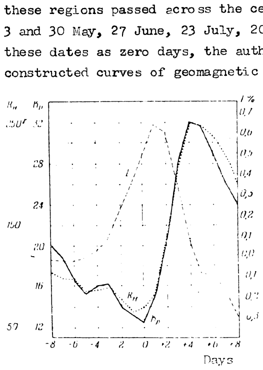


Figure 2

*) The comment by Fedchenko is very interesting; he states that the passage of this unipolar region across the solar disk is accompanied each time by a magnetic storm detected at Bukhta Tikhaya.

remains that at least this unipolar region caused, on earth, a number of magnetic disturbances and increases in the intensity of cosmic rays.

Naturally, similar comparisons between unipolar regions on the sun and various geophysical phenomena must be made using a much greater volume of observational data. The question of identifying M-regions on the sun's surface can be solved only through the processing of such expanded material.

Several words should be said as to the possible causes of decreases in geomagnetic disturbances following the passage across the central meridian of spots devoid of radio emission, spots which form pairs which are symmetrical with respect to the equator and bright coronal regions. In all probability, in these cases there are magnetic fields in active regions, whose intensity and direction are such that they lead to strong deflections of corpuscular streams and to the formation of "rarefications" in continual solar corpuscular radiation.

In conclusion, I would like to note that the question, posed long ago, of the importance of dividing geomagnetic disturbances into two basic types has recently become particularly interesting. Many authors have noted sharp differences between magnetic storms with sudden (Sc) and gradual (G) beginnings. Certain properties of such storms are compared in the table at the end of the article.

Evidently, corpuscular streams which cause magnetic storms with sudden beginning when they strike the earth differ in their physical properties from streams which produce storms with gradual beginnings. Therefore, all comparisons of geomagnetic disturbances with solar activity and other geophysical phenomena (polar aurorae, atmospheric disturbances, tropospheric processes) must be made individually for storms with sudden and gradual beginnings, insofar as possible avoiding those characteristics of magnetic disturbances which do not make such a division possible.

Characteristics	Sc storms	G storms	Authors
Duration	Usually 24-36 hours about 10% last longer than 36 hours.	Sometimes last several days, about 1/3 last longer than 36 hours.	
Nature of the recording on the magnetograph tape	Rapid variations.	Slower variations, usually there is a phase difference between variations in H and D, bays often occur.	Newton and Milson [12]
Aperiodic variation during storm	Often occurs in H.	None.	
Tendency toward 27-day recurrence	Not sharply expressed, as a rule these storms do not form part of a sequence, sometimes they form short sequences.	Sharply expressed, particularly stable and long sequences 1-3 years before the minimum of the 11-year cycle.	Newton and Milson [12]
Change in 11-year cycle	The curve of the number of these storms is very similar to that of the relative number of spots (W), there is no lag with respect to the maximum.	Sharply expressed lag relative to the maximum of the 11-year curve W for ~ 2 years.	
Annual variation	In addition to the equinoctial maxima a third maximum is observed (in summer in northern hemisphere and in winter in southern hemisphere).	Only equinoctial maxima.	Pushkov and Abramova [14] Ol' [13]
Connection with decreases in intensity of cosmic rays (I)	Storms with intensity above a certain limit are always associated with decreases in I.	G storms are not accompanied by decreases in I.	Kitamura [9]

QUESTIONS AND ANSWERS

IA. G. BIRFEL'D. Why do splashes of radio emission begin first in shortwaves and then in longwaves?

A. I. OL'. If we hold to the point of view that splashes of radio emission are generated by corpuscular streams flying through the solar atmosphere, the explanation is as follows: first, the stream generates a splash in the lower layers of the solar atmosphere from which only radio emission in the centimeter and decimeter range can be emitted, and then in the corona, which allows passage of radio waves of the meter and shorter wave range. It should be noted that we do not always observe the sequence of events indicated in the question; the reverse cases are also noted.

N. IA. BUGOSLAVSKAIA. What is the scatter of points in figures 1 and 2?

OL'. Unfortunately, the authors give no statistical estimates of their results. We can, however, make an approximate estimate of the reliability of the curve from the value of the peak on the average curves obtained using the method of superimposing epochs. The statistical results given in the report are sufficiently reliable.

BUGOSLAVSKAIA. How are storms classified?

OL'. In investigations of the connection between solar radio emission and magnetic disturbances, storms are not divided into classes. There are only general indications of a preferable connection between storms with sudden beginnings and spots which have increased radio emission.

K. K. FEDCHENKO. Can we consider that the Babcocks' work has solved the problem of identifying M-regions?

OL'. I think that for a final solution of this problem, we need much more data than that which the Babcocks used.

LITERATURE CITED

[1] Becker, U. Zeitschrift für Astrophysik, 32: 195, 1953.

[2] Becker, U., and J. F. Denisse. Journal of Atmospheric and Terrestrial Physics, 5: 70, 1954.

[3] Bell, B., and H. J. Glazer. Journal of Geophysical Research, 59: 551, 1954.

[4] Bruzek, A. Zeitschrift für Naturforschung, Ser. A, 7: 708, 1952

[5] Bhargava, B. N., and A. M. Naqvi. Nature, 173: 498, 1954.

[6] Babcock, H. W. Astrophysical Journal, 118: 387, 1953.

[7] Waldmeier, M. Zeitschrift für Astrophysik, 27: 42, 1950.

[8] Denisse, J. F. Annales de Geophysique, 8: 55, 1952.

[9] Kitamura, M. Japan. Science Council. Ionosphere Research Committee, Report of Ionosphere Research In Japan, 8: 145, 1954.

[10] Naqvi, A. M., and J. N. Tandon. Indian Journal of Meteorology and Geophysics, 6: 251, 1955.

[11] Newton, H. W. Royal Astronomical Society, Monthly Notices, Geophysical Supplement, 5: 321, 1949.

[12] Newton, H. W., and A. S. Milson. Journal of Geophysical Research, 59: 203, 1954.

[13] Ol', A. I. Priroda, No. 7: 3, 1948.

[14] Pushkov, N. V., and N. V. Abramova. Informatsionnyi Sbornik po Zemnomu Magnetizmu i Elektrichestvu, No. 4: 65, 1937.

[15] Simon, P. Academia des Sciences, Paris, Comptes Rendus, 240: 940, 1906, 1955.

[16] Simpson, J. A., H. W. Babcock, and H. D. Babcock. Physical Review, 98: 1402, 1955.

[17] Smyth, M. J. Observatory, 72: 236, 1952.

DISCUSSIONS ON THE LECTURES BY O. A. BURDO AND A. I. OL'

A. P. NIKOL'SKII. In his lecture, O. A. Burdo presented very interesting results pertaining to magnetic disturbances in high latitudes. The geographic distribution of magnetic disturbances, which up to now has been very complex, has been cleared up considerably thanks to the investigations by Burdo. In the lecture he convincingly showed that this distribution is controlled by relatively simple laws.

From our lecture it is evident that regions with simultaneous appearance of maximum morning disturbances are located in high latitudes along a line which is a spiral emanating from the pole of uniform magnetization and spiraling clockwise. Burdo convincingly showed that regions with a maximum stage of development not only of morning but also of nighttime and daytime magnetic disturbances are also located in high latitudes along lines very similar to two spirals, where both of them turn counterclockwise (both for daytime and nighttime disturbances).

The fact that the regularities which Burdo found are valid both for magnetic activity and for the component of the vector of the magnetic disturbances in the horizontal plane is also worthy of attention. This was pointed out for the first time. Up to now, magnetic activity and the vector of a magnetic disturbance have usually been investigated individually, which is clearly incorrect, methodologically. In this regard, Burdo's results are of very great interest.

Unfortunately, he did not try in any way to explain what determines the occurrence of a magnetic disturbance at a particular point in high latitudes at some position on the spiral. It is clearly insufficient to state, as Burdo did, that this is a function of the appearance of increased conductivity in the ionosphere. However, the cause of an increase in conductivity in the ionosphere remains also as unclear. We know that the phenomenon of a magnetic disturbance is distinguished by its great irregularity and great fluctuations. What are the causes of this irregularity and why the large fluctuation? These are all important questions in the overall problem of magnetic disturbances, but unfortunately they were completely disregarded in Burdo's lecture.

We believe that in solving these problems the concepts of Birkeland and Störmer can be of great help, i.e., the ideas that the controlling factors for the invasion of solar corpuscles into various places of high latitudes are their sign and energy (velocity and mass). Many facts established recently attest to the correctness of these ideas. Several of them were mentioned in our lecture.

The contents of Burdo's lecture can be summed up as follows. He examined which phenomena in the upper layers of the earth's atmosphere could cause the observed effects in the field of a magnetic disturbance, but he is not interested in the reasons for their appearance. In our lecture we devoted our main attention to explaining why magnetic disturbances actually occur at a particular place, and we attempted to explain why the invasion of corpuscles occurs at specific points, and of what this can be a function; but, on the other hand, we did not pay particular attention to the secondary phenomena occurring in the atmosphere as a result of the ~~invasion~~ of solar corpuscles.

It seems to us that the examined problem should be divided into two parts: 1) an explanation of the question as to how solar corpuscles invade the upper layers of the atmosphere, and what determines the location where these corpuscles strike and 2) what processes occur in the upper layers of the atmosphere as a result of the invasion of corpuscles and how these processes cause geomagnetic disturbances. Here, investigations should be so conducted that both sides of the problem are investigated together, connected as closely as possible. Up to now, unfortunately, most of the works suffer from a lack of just such an organic connection. This holds true both with respect to our investigations as well as to Burdo's work.

V. I. KRASOVSKII. Here, several mutually contradictory points of view have been expressed as to the nature of solar corpuscular radiation, and on the results of its influence on terrestrial phenomena. All these viewpoints have been presented in such a form that outwardly it appears that everything is quite satisfactory, while certain discrepancies with fact are non-existent and can be easily eliminated in the very near future. At present, there are actually many interesting and convincing explanations of the various individual sides of the question under discussion. However I must, with all frankness, state that as yet there does not exist an all-inclusive presentation of the whole cycle of questions connected with solar corpuscular radiation and its influence on the earth. In order to construct an exhaustive theory in the indicated direction, at present it is more expedient not to gloss over the existing contradictions with reality, but on the other hand, to expose them with the aim of more rapidly solving them, leaving no room for doubt or inaccuracy.

If we are speaking of the appearance of polar aurorae, then first of all it should be noted that there would still be many things not clear concerning this very simple phenomenon. Thus, e.g., we as yet cannot state that all polar aurorae are connected with the invasion of solar corpuscles – protons. As yet the presence of protons in hydrogen emission has not been established by any means for all forms of polar aurorae. Nevertheless, we definitely must not disregard polar aurorae caused by solar corpuscular radiation of electron composition. Certain arguments in favor of the gas discharge origin of polar aurorae are very convincing; this is caused by induction phenomena which accompany the movement of conducting plasma of solar corpuscular radiation around the earth. It has still not been proved that hydrogen emission cannot be caused by gas discharge phenomena. Hydrogen emission has been most accurately established in the period of the initial stages of the occurrence of quiet arcs. The arc phenomenon itself is extremely interesting since it, evidently, is created by the flat open fan of proton streams when the plane of the fan is located at a certain slight angle to the magnetic parallel. Undoubtedly, this attests to some very unique structure of the initial solar corpuscular stream, or even to something else.

To explain the phenomenon of polar aurorae from the optical point of view, we evidently do not need to assume too high a density of solar corpuscular streams near the earth. For this purpose, most likely, as various authors have pointed out, one corpuscle and less per cm^3 will be sufficient. The assumption of considerably greater density of solar corpuscular streams is not in good agreement with fact. Actually, if we assume that the density of solar corpuscular streams near the earth is high, we necessarily have to assume that in the zone of polar aurorae in the upper layers of the earth's atmosphere a quantity of energy is absorbed which exceeds the energy absorbed in these layers during the day, by many orders of magnitude. The influence of such abundantly absorbed energy would be manifested in a strong increase in the temperature of the upper atmosphere, in the accumulation in it of a large amount of hydrogen brought in from the outside, etc. In order to defend the idea of the high density of corpuscular streams we must completely clearly and convincingly draw the picture of all processes which will occur in the upper atmosphere under these conditions and prove that the proposed picture agrees with that actually observed.

It seems to me that if we disregard the simplified model treatment of electromagnetic phenomena, there is no principal difference between the Bennett-

Hulburt hypothesis and that of Pikel'ner. There can be no different explanations of the passage of one rarefied plasma through another. The difference between the point of view of Bennett-Hulburt and Pikel'ner consists mainly in the quantitative estimates of the corpuscular streams and an ionized gaseous medium. Bennett-Hulburt propose that corpuscular streams have a density of the order of the density of the interplanetary medium, and are formed in the space between the sun and the earth. Pikel'ner considers that solar corpuscular streams may have such a high density that they actually fill the entire interplanetary space, driving out the extraneous ionization medium. From Pikel'ner's point of view, an increase in the density of solar corpuscular streams takes place in the denser ionized medium of the earth's atmosphere. The Bennett-Hulburt viewpoint is more attractive in that it can be associated with less dense solar corpuscular streams. On the other hand, Pikel'ner's opinions raise serious doubts due to the postulation of too high densities of solar corpuscular streams. The Bennett-Hulburt hypothesis, according to which corpuscular streams of fast protons are formed in the space between the sun and the earth, does not explain why the distribution of streams is rectilinear and is not disrupted by magnetic fields in this space. The Pikel'ner hypothesis, which supposes a neutral corpuscular stream, is more acceptable in this regard. Petukhov's hypothesis as to the neutron nature of solar corpuscular streams can also avoid the just mentioned difficulty of the Bennett-Hulburt hypothesis.

If we are speaking of the mechanism of the ejection of corpuscles from the sun, we should state immediately that the explanation of corpuscle ejection by light pressure is in no way convincing. As yet it is completely unclear how atoms from the lower layer of the solar atmosphere can freely penetrate the dense medium of the chromosphere and the corona. Not having explained this, we cannot speak of any possibility of effective light pressure on atoms. Astronomers are very skeptical toward the Petukhov hypothesis of powerful neutron eruptions from the sun. Evidently, there is no sufficient physical basis for postulating that neutron streams reach the earth, since this requires such a high concentration of neutrons on the sun's surface that we can hardly agree with it. However, it seems to me that there is a valuable idea in the Petukhov hypothesis, if we introduce neutrons only to explain the ejection of corpuscles from the lower layers of the solar atmosphere beyond the limits of the chromosphere and the corona. This does not require any inadmissable neutron densities, while the very appearance of neutrons in the solar atmosphere could be explained by other completely possible phenomena. At present it is still impossible to state that on the sun's surface there occur no nuclear reactions or processes generating a small number of neutrons. We also cannot assert that neutrons cannot form as the result of the reaction of protons with neutrinos radiated from the core of the sun or from outside it. Finally, the generation of cosmic rays on the sun also does not exclude the possibility of the formation of neutrons there and, what is more, external cosmic radiation is evidently capable of creating, in the outer layers of the solar atmosphere, the small number of neutrons sufficient to explain solar corpuscular streams of low density, not exceeding several corpuscles per cm^3. In this case, the disintegration of neutrons beyond the limits of the solar corona will lead to the formation of ordinary proton-electron currents which could cause geomagnetic disturbances and polar aururae. Such a modification of the Petukhov hypothesis seems to be more attractive than the hypothesis of the ejection of corpuscles as the result of light pressure.

For a final solution of the problem under discussion, a careful critical study of all viewpoints is necessary, without glossing over the contradictions with fact and with other hypotheses. To establish a valuable theory it is no less important to increase the number and quality of the observations of various manifestations of solar corpuscular radiation and its influence on the earth.

K. K. FEDCHENKO. I would like to make a brief remark regarding A. I. Ol's opinion of the work by Simpson, Babcock and Babcock which he cited: "Unipolar magnetic regions on the sun and their connection with geomagnetic disturbances" (Astrophysical Journal, 121(2): 349, 1955). The lecturer somewhat belittles the value of this work in solving the problem of the identity of Bartels' M-regions. It seems to me that this work is a serious attempt to approach a solution to the indicated problem. On the basis of the results obtained, it is necessary to continue such investigations, particularly during the International Geophysical Year, since during this period a number of stations studying variations in cosmic rays will be equipped with neutron apparatuses.

HYDROGEN RADIATION IN THE SPECTRUM OF POLAR AURORAE

by

S. I. Isaev

I consider it pertinent to report that in the Murman branch of the NIZMIR (Nauchno-issledovatel'skii Institut Zemnogo Magnetizma, Ionosfery i Rasprostraneniia Radiovoln) investigations have begun of the spectra of polar aurorae in the visible region.

In the winter and fall of 1955 (January, February, March and October) A. E. Veller obtained more than twenty spectra on the diffraction spectrograph (f:1.2, dispersion 330 Å/mm). These spectra are still being processed.

A preliminary analysis of these spectra has shown that in a number of spectrograms the H_α hydrogen line has been detected both shifted and not shifted toward the violet due to the Doppler effect, depending on the orientation of the instrument with respect to the earth's magnetic field.

Hydrogen appeared very clearly with the photographing of diffuse arcs, diffuse bands and diffuse luminescence.

Molecular nitrogen shows up strongly with radial forms of the aurorae and in this case we can not say definitely whether the H_α line appears; it can be greatly masked by the positive nitrogen system. The maximum velocity of the hydrogen atoms responsible for the excitation of the aurorae was determined from Doppler shifting of the H_α line (of the order of 60 Å); it proved to be approximately 3000 km/sec, which agrees with the data of Meinel and Gartlein.

Below we give several spectra of aurorae with the H_α line in the sequence in which they were obtained.

Figure 1 shows two successive spectra of polar aurorae taken during the night of 18-19 February 1955 during a typical polar magnetic storm from 2200-0300 Moscow time (from now on, all times will be expressed in Moscow time).

The upper spectrum was obtained at the start of the development of the aurorae, when unified arcs prevailed, the lower spectrum during the strong flare of the aurorae (drapery, corona, arc). The H_α line is clearly visible in the first spectrum, but in the second it is difficult to detect because of the strongly developed nitrogen system. Figure 2 gives three successive spectra of polar aurorae taken on the night of 10-11 March 1955 during a large magnetic disturbance. All three spectra were taken in the zenith from 2130 through 0330. Bright forms were photographed in the upper spectrum during the first hour of exposure. During the second hour, weak diffuse illumination was photographed; H_α is absent (or is masked). The middle spectrum was exposed for three hours (2330-0230). Diffuse illumination and bands were photo-

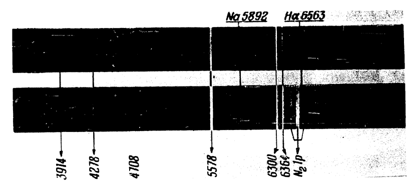


Figure 1

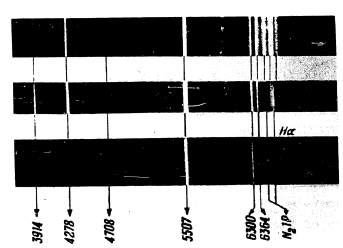


Figure 2

graphed in the zenith. H_α is present (there is an increase in the nitrogen band due to the superposition of hydrogen radiation). The bottom spectrum was also exposed three hours (0230-0530). Weak diffuse illumination was photographed; H_α is absent.

The spectrum given in figure 3 was taken on 22 March 1955 (also during a large magnetic storm) with an exposure of 1^h30^m (2230-0000). During exposure, diffuse bands predominated. Intense hydrogen radiation is visible in the spectrum.

Figure 4 gives a spectrum of an aurora taken on the night of 22-23 October 1955 during a weak magnetic disturbance which occurred from 2232-0245. Weak illumination on the northern horizon was photographed. The hydrogen line is clearly visible in the spectrum.

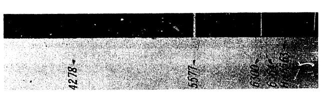


Figure 3

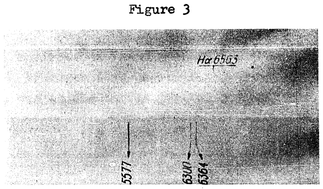


Figure 4

A preliminary analysis of the aurorae spectrum obtained during various phases of the development and for various forms near the zone of polar aurorae gives grounds for assuming that hydrogen atoms (protons) constantly appear, but when the charge associated with the advance of protons becomes large at the level of the E layer of the ionosphere there is a vertical discharge which is manifested as radial forms. At this time hydrogen cannot be detected because of the masking of H_α by the intense radiation of the nitrogen bands. As soon as the vertical discharge ceases, hydrogen is once more detected in regular forms.

These conclusions are being verified. Work along this line is being continued. A detailed analysis of the spectra obtained will be published at a later date.

The conclusions that have been drawn hypothetically in this article are supported to a certain degree by radio observations of polar aurorae conducted in Alaska in 1954 (K. L. Bowles. Journal of Geophysical Research, 59(4): 533-555, 1954).

The signals reflected from the aurorae revealed Doppler shifting of frequency f. Shifts toward lower frequencies are well correlated with regular forms of aurorae. In this case, in the author's opinion, reflection is caused

by the scattering by free electrons which move along magnetic lines of force. The author is inclined to interpret the shift toward high f (receding movement) as a charge directed from the earth's surface. The charge (radial forms) occurs when the charge at the level of the E layer becomes extremely large.

It has been proposed that at the NIZMIR during the IGY, in addition to other research, systematic study will be organized of the hydrogen radiation in the spectrum of polar aurorae.

THE EQUATION OF QUASISTATIONARY IONIZATION EQUILIBRIUM IN THE F 2 REGION AND SOLAR CORPUSCULAR RADIATION

by

E. I. Mogilevskii

1. The role of solar corpuscular radiation in the ionization of the ionosphere, particularly during disturbed periods, has been repeatedly examined in literature, mainly from the point of view of explaining the phenomenon of polar aurorae. The investigation of corpuscular ionization in the F2 region has been mainly qualitative. Several well-founded quantitative estimates of the intensity of solar corpuscular radiation which would follow from ionospheric data were not obtained; nevertheless, there is a large amount of observational data which attests to the considerable role of corpuscular ionization in the ionosphere. These are features of the daily and seasonal variations of ionization and also the variation of ionization during the solar cycle in the F2 region in middle and, in particular, high latitudes, the nature of the behavior of ionospheric disturbances, etc. A theory of ionospherio-magnetic disturbances cannot be constructed without a quantitative analysis of the ionizing role of solar corpuscular radiation. The results of this analysis should provide a basis for a better approach to the question of the comparison of the ionospheric data with phenomena in active regions of the sun. The aim of the present article is to establish a method for the quantitative estimate of the ionizing role of corpuscular radiation for ionospheric data and the possibility of obtaining from these results certain characteristic parameters of solar corpuscular streams.

In the F2 region of the ionosphere the equation of ionospheric equilibrium

$$\frac{dn_-}{dt} + \alpha n_-^2 = Q \qquad (1)$$

(n_- is electron concentration and α the effective coefficient of recombination) during disturbances should be solved for the ionizing function $Q(t)$, a function of time. In this case, equation (1) becomes nonlinear and does not have a clear solution. Making the substitution

$$n_- = \frac{1}{\alpha y}\frac{dy}{dt} \qquad (2)$$

we get equation

$$\frac{d^2y}{dt^2} = \alpha y Q(t) \qquad (3)$$

whose solution can be found in the form of the series

$$y = (y_0 + \alpha^{-1/2}y_1 + \alpha^{-1}y_2 + \ldots)\exp[-\alpha^{1/2}\Phi(t)]. \qquad (4)$$

Substituting (4) in (3) with arbitrary α gives a system of subsequent inequalities:

$$\left.\begin{aligned} &\left[\left(\frac{d\Phi}{dt}\right)^2 - Q\right]y_0 = 0, \\ &\frac{d^2\Phi}{dt^2}y_0 + 2\frac{d\Phi}{dt}\frac{dy_0}{dt} = 0, \\ &\frac{d^2\Phi}{dt^2}y_1 + 2\frac{d\Phi}{dt}\frac{dy_1}{dt} = \frac{d^2y_0}{dt^2}, \\ &\ldots\ldots\ldots\ldots\ldots \end{aligned}\right\} \qquad (5)$$

The solution of this system of differential equations determines the values of y_i in series (4). The rapid convergence of the series is assured when there is a relatively slow change in the ionization function.

This latter is given by the inequality

$$\frac{dQ}{dt}t_0 \ll Q. \qquad (6)$$

where t_0 is the examined time interval. When the indicated condition of quasistationarity is fulfilled which, as is easily seen, can be done in the F region of the ionosphere, we may limit the solution of (1) to two terms:

$$n_- = \left(\frac{Q}{\alpha}\right)^{1/2} - \frac{1}{4\alpha}\frac{\frac{dQ}{dt}}{Q}. \qquad (7)$$

When $dQ/dt \approx 0$ we get the ordinarily accepted solution of the equation of ionization equilibrium. Numerical estimates for the F2 region show that even during relatively weak ionospheric disturbances the second term becomes comparable with the first term. The obtained solution of the equation of quasistationary equilibrium*) can be of essential value when analyzing ionospheric conditions during undisturbed periods as well (e.g., when analyzing the daily variation of ionization, examining the results of ionospheric observations during solar eclipses, etc.). Moreover, it is evident that when examining ionization equilibrium during disturbances, when the ionization function changes due to the variations in the intensity of solar ionizing radiation

*) Part of the present work, in which the solution of the equation of quasistationary equilibrium was obtained, was done at the Scientific Research Institute of Terrestrial Magnetism in 1949.

and possible changes in the ionospheric conditions themselves, it is necessary to use the solution of the equation of quasi stationary equilibrium (7).

In the general case, the ionizing function can be represented by two components, caused by wave and corpuscular ionization radiation of the sun:

$$Q = \int [F_\nu(t,z)\, B_\nu \cos\chi + I_\varepsilon(t,z)\, \sigma\psi(t,\beta)]\, n^0(z)\, dz. \qquad (8)$$

Here $F_\nu(t,z)$ is the intensity of solar wave radiation with frequency $\nu > \nu_0$, where ν_0 is the limiting frequency of ionization for the active*) component of the layer, B_ν is the Einstein coefficient of the probability of induced photoionization of the active component of the layer, χ is the zenith distance of the sun, $I_\varepsilon(t,z)$ is the intensity of corpuscular ionizing radiation, σ the effective cross section of corpuscular ionization, $\psi(t,\beta)$ the factor which determines the atmospheric equivalent, which takes the movement of ionized corpuscles in the earth's magnetic field into account, β is the geomagnetic declination, and $n^0(z)$ the concentration of the active component of the ionosphere.

For analyzing corpuscular ionization we may choose those conditions under which the first term can be disregarded with sufficient approximation. Such conditions are realized, e.g., during the night in the middle and particularly the high latitudes during disturbances. In this case, without giving any specific ionization mechanism we assume that solar corpuscular radiation operates directly in the zone of aurorae and directly or indirectly in regions adjacent to the aurorae. In order to get an idea of the parameters of the solar corpuscular stream from ionospheric data, which pertain to the level of the maximum ionization of the layer, we must consider the change in the intensity of the ionizing stream when passing through the entire upper layer up to the maximum ionization of the F2 region.

The change in the intensity $I_\varepsilon(t)$ of the corpuscular stream when passing through layer dz will be

$$dI = I_\varepsilon(z,t)\, n^0(z)\, \sigma\psi(t,\beta)\, dz. \qquad (9)$$

If we assume that charged solar corpuscles approach the magnetic lines of force at an angle $\delta(t)$, the effective atmospheric equivalent will be determined by the expression

*) In other words, atoms and molecules of the atmosphere which basically undergo ionization at given heights.

$$\psi(t,\beta)\, dl = \sec\delta(t)\sec\beta\, dz. \qquad (10)$$

The distribution of the concentration of active atoms with height can be represented by the equilibrium formula

$$n^0(z) = n^0_m \exp\left(-\frac{mg}{k}\int_0^z \frac{dz}{T}\right). \qquad (11)$$

where n^0_m is the concentration of active atoms with mass m at the level of maximum ionization, taken as the level of the start of height computation z = 0, k is the Boltzmann constant, and T is the temperature at the examined level. If we assume the following temperature distribution with height

$$T = T_m(1 + az), \qquad (12)$$

where a is the positive temperature gradient with height (usually $\sim$ 4-8° km^{-1}) and T_m is the temperature of the level of maximum ionization, we get

$$n^0(z) = n^0_m (1 + az)^{-b}, \qquad (13)$$

where

$$b = \frac{mg}{kT_m a}. \qquad (14)$$

Substituting expressions (10) and (13) in (9) and integrating, we get

$$I_\varepsilon(t,z) = I_\infty(\varepsilon,t)\exp\left[-\frac{n^0_m\sigma\sec\delta(t)\sec\beta}{a(1-b)}(1+az)^{(1-b)}\right], \qquad (15)$$

where $I_\infty(\varepsilon,t)$ is the intensity of the solar corpuscular stream beyond the limits of the earth's atmosphere. The ionization function q, caused by corpuscular ionization at the level of the maximum layer, will be

$$q_m = \int_{\varepsilon_1}^{\infty} I_\varepsilon(t,z)\, \sigma n^0_m\, d\varepsilon, \qquad (16)$$

where ε_1 is the energy of ionization of the active atoms of the layer. Substituting expression (15) into (16) we get

$$q_m = n^0_m\sigma\exp\left(-\frac{n^0_m\sigma\sec\delta(t)\sec\beta}{a(1-b)}\right)\int_{\varepsilon_1}^{\infty} I_\infty(\varepsilon,t)\, d\varepsilon \qquad (17)$$

Substituting the magnitudes q_m and dq_m/dT in formula (7) for the electron concentration at the level of maximum ionization with quasistationary equilibrium we get (the subscripts are omitted)

$$n = -\frac{1}{4\alpha}\left[\frac{1}{n^0}\frac{dn^0}{dt}\left(1 - 2\frac{n_0 \sec\delta \sec\zeta}{a(1-h)}\right) - \frac{d\delta}{dt}\frac{n_0\sigma \sec^2\delta \operatorname{tg}\delta \sec\zeta}{a(1-h)} + \frac{\int_{\varepsilon_1}^{\infty}\frac{d}{dt}(I(\varepsilon,t)\,d\varepsilon}{\int_{\varepsilon_1}^{\infty} I(\varepsilon,t)\,d\varepsilon}\right] + \left[\frac{n^0\sigma}{\alpha}\int_{\varepsilon_1}^{\infty} I(\varepsilon,t)\,d\varepsilon \cdot \exp\left(-\frac{n^0\sigma \sec\delta \sec\zeta}{a(1-h)}\right)\right]^{2} \tag{18}$$

Expression (18), because of the small value of the effective cross section of ionization σ, can be simplified somewhat and given in the form

$$n = -\frac{1}{4\alpha}\left[\frac{1}{n^0}\frac{dn^0}{dt} - \frac{d\delta}{dt}\frac{n^0\sigma \sec^2\delta \operatorname{tg}\delta \sec\zeta}{a(1-h)} + \frac{\int_{\varepsilon_1}^{\infty}\frac{d}{dt} I(\varepsilon,t)\,d\varepsilon}{\int_{\varepsilon_1}^{\infty} I(\varepsilon,t)\,d\varepsilon}\right] + \left(\frac{n^0\sigma}{\alpha}\int_{\varepsilon_1}^{\infty} I(\varepsilon,t)\,d\varepsilon\right)^{2}. \tag{18'}$$

An examination of expression (18') shows that the electron concentration at the level of maximum ionization can be examined as consisting of two parts: n_{reg} and n_{irreg}. The first of these

$$n_{reg} = -\frac{1}{4\alpha}\left[\frac{1}{n^0}\frac{dn^0}{dt} - \frac{d\delta}{dt}\frac{n^0\sigma \sec^2\delta \operatorname{tg}\delta \sec\zeta}{a(1-h)}\right] \tag{19}$$

changes regularly and is mainly a function of the ionospheric conditions proper, and the second

$$n_{irreg} = -\frac{1}{4\alpha}\frac{\int_{\varepsilon_1}^{\infty}\frac{d}{dT} I(\varepsilon,t)\,d\varepsilon}{\int_{\varepsilon_1}^{\infty} I(\varepsilon,t)\,d\varepsilon} + \left(\frac{n^0\sigma}{\alpha}\int_{\varepsilon_1}^{\infty} I(\varepsilon,t)\,d\varepsilon\right)^{2} \tag{20}$$

is determined from the form and changes of the energy spectrum of the solar geoeffective stream of corpuscles. Such a classification can be made using the corresponding method of processing ionospheric observational data. Let us introduce an expression for the energy spectrum of solar corpuscular streams in the form

$$I(\varepsilon,t)\,d\varepsilon = N(t)\,\varepsilon^{-\gamma}\,d\varepsilon. \tag{21}$$

whose parameters $N(t)$ and γ can be determined experimentally. Such a type of energy spectrum must be chosen because of consideration of the interaction of a corpuscular stream with the upper corona and the interplanetary medium, because of the possible statistical mechanism of the generation of the stream, the necessity of "sewing together" the spectrum of cosmic rays during solar flares and the spectrum of the geoeffective corpuscular stream, etc. Substituting (21) in (20) and integrating, we get

$$n = \frac{1}{4\alpha}\left[\frac{d\gamma}{dt}\left(\ln\varepsilon_1 - \frac{1}{1-\gamma}\right) - \frac{dN}{dt}\Big/N\right] + \left(\frac{n^0\sigma}{\alpha}\frac{N\varepsilon_1^{1-\gamma}}{1-\gamma}\right)^{2} \tag{22}$$

In first approximation, as can be easily seen, the second term can be disregarded. This gives

$$n = \frac{1}{4\alpha}\left[\frac{d\gamma}{dt}\left(\ln\varepsilon_1 - \frac{1}{1-\gamma}\right) - \frac{dN}{t}\Big/N\right]. \tag{23}$$

Let us examine the case $d\gamma/dt = 0$, i.e., when the form of the energy spectrum of a corpuscular stream does not change with time. Then, after integrating, we get

$$N_i = N_0 \exp(-4\alpha n_i t_i). \tag{24}$$

where n_i is the irregular disturbed part of the electron concentration in the F2 layer at the level of maximum ionization at moment t_i at the selected observation point. A series of measured values of n_i makes it possible to trace variations of the parameter N_i in the corpuscular stream. It is not difficult to see that even very noticeable changes of N_i in the corpuscular stream do not lead to large changes of n_i, i.e., in the F2 layer during disturbances we should not observe very rapid and large fluctuations of electron concentration. This explains the quasistability of the ionosphere during disturbances, which has been deduced from observations. If we examine different values of Δn_i (at definite moments of time t_i) for ionospheric stations located in a limited region where the ionospheric parameters change uniformly (during individual periods of ionospheric disturbances such regions can be identified when examining synoptic ionization charts), assuming that $d\gamma/dt \neq 0$ in (23), after integration we get the following expression

$$A\gamma + \ln(1-\gamma) = 4\alpha\beta_i t_i. \tag{25}$$

where

$$A = \ln \varepsilon_1 \text{ and } \beta_i = \Delta^{-} n_i$$

Thus, a system of values of the average ionospheric difference data $\Delta^{-} n_i$ for a definite territory makes it possible to trace a change in the magnitude γ. Preliminary computations have shown that the magnitude $\gamma \sim 0.6$ and, evidently, changes very little during disturbances. Summing up, we may state that during the corresponding processing of ionospheric data we may turn to a quantitative estimate of the stream parameters. Any theory of the emission of corpuscular streams from active regions of the sun should first of all explain the observed energy spectrum of the stream and its possible time variations.

The validity of such an approach to the problem is confirmed by the fact that from the very solution of the equation of quasi stationary ionospheric equilibrium there follows the relative stability of the ionosphere during disturbed periods, which can be confirmed by statistical ionospheric data.

APPENDIX

Since the solution (7) of the equation of ionization equilibrium (1), providing the ionization function Q(t) changes with time, can have a number of addenda, let us show the solution in somewhat more detail. We will seek a solution of equation (3), as shown above, in the form of a series (4) which gives, after substitution in (3), the system of equations (5). The first two equations of (5)

$$(Q - \Phi'^2) y_0 = 0. \tag{26}$$

$$y_0' + \frac{\Phi''}{2\Phi'} y_0 = 0 \tag{27}$$

are easily integrated.

Since $y_0 \neq 0$, from (26) it follows that

$$Q = \Phi'^2 \text{ or } \Phi = \int_0^t \sqrt{Q}\,dt. \qquad (28)^{*)}$$

where 0 is the conditional moment of the start of the disturbance or the zero fixed reading of the examined time interval.

Integrating (27) we get

*) Obviously, t cannot be less than zero.

$$y_0 = \frac{C}{\sqrt{\Phi'}} = \frac{C}{\sqrt[4]{Q}} \tag{29}$$

where C is the integration constant. Then, as will be shown below, series (4) can be limited to the first term. Substituting (28) and (29) in (4), we get

$$y = \frac{C}{\sqrt[4]{Q}} \exp\left(i \int_0^t \sqrt{Q}\,dt\right). \tag{30}$$

And, finally, substituting (30) in (2) we get the desired solution of equation (7).

The third equation of (5) makes it possible to estimate the magnitude y_1 and thus determine the representitivity of the approximate solution (7). Let us assume that the solution for y_1 has a form analogous to expression (29) for y_0, where C will be a function of time, i.e.,

$$y_1 = C(t)\,|\Phi'(t)|^{-1/2}. \tag{31}$$

Then, substituting (31) in the third equation of (5) we get

$$2(\Phi')^{1/2} C' = y_0''. \tag{32}$$

whence

$$C = \int_0^t \frac{y_0''}{2(\Phi')^{1/2}}\,dt. \tag{33}$$

Then,

$$y_1 = \frac{1}{(\Phi')^{1/2}} \int_0^t \frac{y_0''}{2(\Phi')^{1/2}}\,dt. \tag{34}$$

If we substitute in (34) the expression for y_0'' which follows from (29) we get

$$y_1 = C(\Phi')^{-1/2} \int_0^t \left\{ \frac{3}{8} \Phi''^2 (\Phi')^{-5/2} - \frac{1}{4} \Phi''' (\Phi')^{-3/2} \right\} dt. \tag{35}$$

From (35) we get

$$\frac{y_1}{y_0} = \int_0^t \left\{ \frac{3}{8} \left(\frac{dQ}{dt}\right)^2 Q^{-5/2} - \frac{1}{4} \frac{d^2Q}{dt^2} Q^{-3/2} \right\} dt. \tag{36}$$

Partial integration gives

$$\frac{y_t}{y_0} = -\frac{1}{4} Q^{-2}\frac{dQ}{dt}\Big|_0^t - \frac{1}{8}\int_0^t \left(\frac{dQ}{dt}\right)^2 Q^{-3}dt = \\ = -\frac{1}{4} Q^{-2}\frac{dQ}{dt}\Big|_0^t - \frac{1}{8}\int_0^t \frac{dQ}{dt} Q^{-2} d\ln Q. \tag{37}$$

Let Q be a monotonous function. Then dQ/dt and d ln Q have the same sign for the interval (O,t). From this it follows that

$$\int_0^t \frac{dQ}{dt} Q^{-2} d\ln Q \leqslant \left(\frac{dQ}{dt} Q^{-2}\right)_{\max}(\ln Q)_{\max}. \tag{38}$$

Multiplying both sides of equality (37) by $\alpha^{-1/2}$ and considering (38), we get

$$\alpha^{-1/2}\frac{y_t}{y_0} \leqslant \alpha^{-1/2}\left\{-\frac{1}{4}\frac{dQ}{dt}Q^{-2}\Big|_0^t - \frac{1}{8}\left(\frac{dQ}{dt}Q^{-2}\right)_{\max}(\ln Q)_{\max}\right\} < \\ < -\frac{\alpha^{-1/2}}{4}\left(\frac{dQ}{dt}Q^{-2}\right) - \frac{1}{8}\alpha^{-1/2}\left(\frac{dQ}{dt}Q^{-2}\right)_{\max}(\ln Q)_{\max} < \\ < -\frac{\alpha^{-1/2}}{4}\left(\frac{dQ}{dt}Q^{-2}\right)_{\max} - \frac{\alpha^{-1/2}}{8}\left(\frac{dQ}{dt}Q^{-2}\right)(\ln Q)_{\max}. \tag{39}$$

Or,

$$\alpha^{-1/2}\frac{y_t}{y_0} \leqslant -\frac{\alpha^{-1/2}}{8}\left(\frac{dQ}{dt}Q^{-2}\right)_{\max}[2 + (\ln Q)_{\max}]. \tag{40}$$

In order that solution (30) containing the first term of series (4) be sufficiently representative, inequality

$$\alpha^{-1/2} y_t y_0^{-1} \ll 1. \tag{41}$$

must be fulfilled. According to (40), fulfilling inequality (41) is equivalent to fulfilling the following two inequalities:

$$\alpha^{-1/2}\left(\frac{dQ}{dt}\right)_{\max} \ll 8\, Q^{T2}_{\max} \tag{42}$$

$$(\ln Q)_{\max} \geqslant 2 \tag{43}$$

Condition (42) is fulfilled if we examine "slow" changes in function Q in the sense of the determination given by inequality (6). Inequality (42) can be examined as a specification of the condition that a chan[illegible] n the ionization function Q is slow.

QUESTIONS AND ANSWERS

I. S. SHKLOVSKII. How do you picture the ionization mechanism?

E. I. MOGILEVSKII. As I have already reported, when solving the equation of ionization equilibrium in the ionosphere and when applying it to an estimate of the characteristic parameters of the corpuscular stream, it was not necessary to introduce any specific mechanism of the interaction of solar corpuscles of the stream with atoms (molecules) of the ionosphere. The interaction mechanism must be made more specific when using the definite value of the effective diameter of the ionization of ionospheric atoms by solar corpuscles. When examining the ionization of the F2 region of the ionosphere, the energy (and, accordingly, the velocity) of corpuscles is relatively low ($V \sim 5 \times 10^7$ cm x x sec^{-1}). We cannot consider that in our case, e.g., there is an active recharging mechanism since in this case one would have to observe conspicuous hydrogen illumination of the entire F layer even in the middle latitudes. Assuming that we have a mechanism of impact ionization by relatively slow heavy corpuscles, we find that the mean concentration in the stream should be $\gtrsim 10^2$ cm^{-3}.

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